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General Astronomy.

PREDICTION REGARDING THE SOLAR CORONA OF THE TOTAL ECLIPSE OF APRIL 15-16, 1893.*

FRANK H. BIGELOW.

I shall venture to make the following prediction regarding the position of the corona of April 15-16, 1893, as seen by an observer on the Earth, including also the places of the coronal poles, and the relative distribution of the stream lines in the corona itself. Using the following notation and elements:

N, the ascending node of the Sun's equator on the ecliptic, 74°.

I, the inclination of these planes, 7° 15′.

W, the inclination of the Earth's orbit, 23° 27′.3, we have,

L, the heliographic longitude of the Earth or center of disk, 313° 2′.5.

D, the heliographic latitude of the Earth or center of disk, — 5° 18′.7.

If K is the pole of the ecliptic,
S the pole of the Sun's axis,
E the pole of the Earth's axis,
C the pole of the corona,

and their projections on the plane perpendicular to the line of vision, passing through the center of the Sun, K, N, P, M, respectively, and if O is the apparent center of the disk, then the angles,

$$\begin{aligned} H &= KOS = 4^\circ\ 56'.5, \\ G &= EOK = 21^\circ\ 10'.1, \\ \text{and } H + G &= EOS = 26^\circ\ 6'.5. \end{aligned}$$

Co-ordinate angles from the Sun's axis being taken as positive in both hemispheres towards the west, and negative towards the east; as positive on the earthward side of the plane of projection, and negative on the opposite side, the co-ordinates of the coronal poles referred to the plane passing through KO, perpendicular to the line of vision; and to the plane through SO, including the line of vision, will be:

* Communicated be the author.

for the north coronal pole, $NM = - 4\frac{1}{2}°$, east,
$MC = - 5°$, back;
for the south coronal pole, $NM = + 1°$, west,
$MC = + 8\frac{1}{2}°$. front.

Hence the heliocentric longitude of the Earth being 208°, that of the north coronal pole will be 108°, and that of the south coronal pole will be 214°, approximately.

The following diagram results from projecting orthogonally the north polar regions of the Sun downwards upon the plane of the ecliptic, and the south polar regions upwards upon the same plane.

The diagram of the stream lines in the corona is obtained by projecting the shadow of the model of the Sun and its corona, already described, upon a screen, after it has been placed in position by the following data, due to a method not yet published. Take June 12.22, 1887, as the epoch when the south pole of the corona is in the plane passing through the centers of the Sun and the Earth perpendicular to the Ecliptic, and between the Earth and the Sun, then the synodic period 26.68 days gives April 15.60, 1893, as the next preceding recurrence before the eclipse. The diagram explains itself quite clearly so that a description of it is not needed here. The figures on the outer circle are the angles, counted from the axis K, to the middle of the bunch of overlapping stream lines superposed in projection, those on the inner circle referring to the axis S. In pictures of the corona, these concentrations appear as the quadrilateral projections, and will not generally show individual stream lines. Such rays as are separated from each other, for the most part cluster around the poles within these bunches, although sometimes a line or two can be made out on the equatorial side of them.

The diagram cannot hope to represent the exact lines that may appear at the eclipse, for obvious reasons, but it may succeed in showing the general distributions of the lines as regards the poles of the Sun or of the ecliptic. Thus, the compressed side of the corona is eastward, and the open side westward of the disk of the Sun; the N. E. quadrant should appear thin and short, but the N. W. fuller and longer as to its lines, the two southern quadrants being more symmetrically disposed.

I fear that at the eclipse of 1893 the conditions of solar output will be so intense as to obscure the lines entirely, because the only photographs of the corona that are available for measures were secured at times of the minimum eruptive energy of the Sun, namely in 1878 and 1889. I shall look on that date, April 16, 1893, also for spottedness of the Sun's surface above the average for magnetic and auroral disturbances, and for marked changes in the barometric pressures from high to low throughout the northern hemisphere.

It should be remarked that the data thus furnished are more a test of the accuracy of my epoch and period of rotation of the Sun than of the theory of its physical constitution that I have advocated in earlier papers on the corona.

In order to obtain valuable photographs of the stream lines of the corona for measurements it is essential that the telescope used have a long focus, more than ten feet if possible; also it is shown by experience that all such good pictures have been taken with rather short exposures, usually under three seconds; and furthermore the best emulsions for holding the inner and the outer regions of the corona, without burning the inner parts, have been made with collodion and not with gelatine.

NOTE ON THE PROBABLE ORIGIN OF HOLMES' COMET.*

SEVERINUS J. CORRIGAN.

In quest of the identity of the celestial bodies which have, probably, been in collision and thereby produced Holmes' comet according to the hypothesis which I have enunciated in No. 111 of ASTRONOMY AND ASTRO-PHYSICS, I have completed the examination of the list of those asteroids whose elements have been determined, whose number now exceeds three hundred.

The process of examination was very simple. I assumed that the *hypothetical* collision occurred on, or shortly before, the date of discovery, Nov. 6, 1892.

In support of this assumption I adduce the fact that this comet when discovered was of such considerable dimensions and brightness, that it surprised the discoverer, who had examined the same immediate region of the heavens in which this body was discovered, only twelve days before he found the latter, without seeing anything that would indicate the approach of so conspicuous an object, a fact which cannot be accounted for by the hypothesis of a rapid approach of the comet to either the Sun or the Earth, because the elements clearly show that on Nov. 6 and thereafter, it was receding from instead of approaching both those bodies.

* Communicated by the author.

Furthermore the rapid expansion of the volume of the comet, shortly after the time of discovery, indicates very clearly that the catastrophe could not have occurred *very* long before that time.

From the elliptic elements computed by Rev. Geo. M. Searle, and given in the last number of this magazine, I have found that the radius vector of this comet was on Nov. 5.0, approximately, 2.286, the heliocentric longitude nearly 35°, and the heliocentric latitude about + 18°. The next step was, obviously, to find if possible, such of the known asteroids whose radii-vectores and heliocentric longitudes and latitudes were the same, or nearly the same, on Nov. 5.0, 1892, as those of the comet on the same date.

The well-known relation between the longitude, l, the latitude, b, the inclination, i, and the node, ☊, expressed by the equation, $\tan b = \tan i \sin(l - ☊)$, furnishes one criterion by which the question of the retention or rejection of any asteroid as a possible component of the comet, can be rapidly decided. In the first place, it is plainly apparent that no asteroid whose inclination lies below about 18°, is admissible; therefore, a large majority of those on the list were rejected on mere inspection.

Furthermore, the equation shows that for each inclination above 18°, there must be two definite positions (corresponding to the angle $(l - ☊)$ and to its supplement) which the node of any asteroid must occupy in order that such body could be, at any time, at the point where the comet was on Nov. 5.0, and where the collision is assumed to have occurred. This condition caused the rejection of a majority of the bodies retained after the first inspection. Only the computation of the heliocentric longitude and latitude and finally of the radius-vector of each of the very few residual asteroids, was then necessary to complete the examination, the result of which was negative; no asteroids were found that fulfilled all the necessary conditions. If the known asteroids constitute the entire group, this result would be fatal to the hypothesis which I have advanced. But there is sufficient evidence to demonstrate that the number of these bodies cannot be limited to any small amount. If the number discovered decreased with each succeeding year, we might infer a quite moderate limit, but the discoveries have gone on from year to year, with frequency quite undiminished; therefore, the limit of the numbers must be very great.

Furthermore, it is reasonable to suppose that the vast space between the orbits of Mars and of Jupiter should contain much matter, if not in the form of a considerable planet at least in that of a group of small planetary bodies, such as the asteroids are known to be.

Now, while the diameter of the smallest known asteroid cannot be well determined by actual measurement, yet judging by magnitude, and the ordinary light reflecting power, it is probably below 20 miles, and very likely much below that amount. Therefore, it would require more than 9,000,000 of such masses to constitute a body equal even to the small planet Mars. Of course, I do not mean to say that there are that many asteroids, but only to show that their number is probably very great. I think that it will not be considered unreasonable to assume that the number of smaller asteroids, quite beyond the reach of the telescope, may be reckoned by tens of thousands. I would liken the whole group of these bodies to the rings of Saturn which are probably composed of a vast number of minute satellites.

Admitting, therefore, that the number of undiscovered asteroids is very great as compared with those discovered and whose elements are known, it is at once apparent that the *probability* that the component bodies, forming the comet, were *undiscovered* asteroids is, practically, equivalent to a certainty. Therefore, while the negative result of my examination of the list of the known members of the group diminishes the probability of the truth of the hypothesis which I have advanced in regard to the origin of Holmes' comet, the diminution is so small that this hypothesis is not materially affected thereby; the only consequence is that it must ever remain a hypothesis pure and simple.

The probability of its truth must depend upon the fact that the cometary elements are such that they might well represent those of a member of the asteroid group, and upon the further fact that under no other hypothesis can the anomalous phenomenon of an increasing apparent diameter and an increasing geocentric distance be so rationally and satisfactorily explained. True, it might, with some show of reason, be conceived that this comet is the result of the *explosion* of a single asteroid, but the difficulty of determining the probable cause of such an explosion would be much greater than that of the original problem; the supposition of a collision is much more tenable. Theoretically, even such a catastrophe must be one of extreme infrequency, and this is illustrated by the fact that in the whole history of astronomy no such peculiar phenomena as those connected with the Holmes' comet, have been noted. There is also naturally suggested, in this connection the kindred hypothesis that some of the comets of short period, notably Faye's, D'Arrest's and Tempel's may have had their origin, likewise, in the collision of members of the group of asteroids.

St. Paul, Minnesota, Jan. 7, 1893.

ASTRONOMY IN 1893.

WM. W. PAYNE.

More than one month of the new year will have passed before these suggestions will be read by those for whom they are intended. In the January issue of this publication little was said about changes or plans for 1893, because they were not definitely arranged then; neither are they completed now so as to speak of them in detail satisfactorily. However something will be indicated in this brief article regarding the place this periodical may fill before we are done, after other suggestions are made concerning the outlook for Astronomy for the year 1893.

One noticeable feature of the present status of practical or observational astronomy is the multiplication of good and useful astronomical instruments. The increase in size, the various kinds and the expensive outlays for such equipments indicate something of the plane of activity of prevailing thought that concerns immediate plans for the benefit of astronomical science in general. The founding of Lick Observatory a few years ago, a similar unsuccessful attempt later by the University of the Pacific at Los Angeles, the planning of the 10-foot mirror in France, the 40-inch refractor in process of construction by Mr. Alvan Clark of Cambridgeport, Mass., at the present time for the Yerkes Observatory of the University of Chicago, besides other mammoth schemes in the interest of astronomy not yet made public, sufficiently show the drift of public thought in regard to the tools of the astronomer for modern research. This means very much for science when it is remembered that the large sums of money necessary for these grand enterprises come, in most cases from persons of wealth, not especially skilled in science, but who have intelligent and hearty interest in its true and rapid progress in almost every way that meets the approval of men having recognized ability in astronomy. A person can not be mistaken concerning the breadth of this philanthropic spirit, when he notices that there is a demand at Roberts' College, in Turkey, for a supply of astronomical instruments which will cost $10,000.

The money has been given, and the instruments are now being made in this country for that college. A like request has already come from Anatolia College, at Marsovan, Turkey, for a similar outfit of instruments, and it must and will be met promptly. In this last case an Armenian scholar has been in special training for nearly three years, in a post-graduate course in mathematics and astronomy at the Goodsell Observatory of Carleton College, for the purpose of fitting himself thoroughly for instruction and practical work in these branches in Anatolia College.

This suggests also the fact that more attention is being given to the proper training of teachers and scholars in mathematics and astronomy during the last three years than previous to that time. Able astronomers and mathematicians are in demand in professional life, at fair or inviting salaries, and they have little time to give to the instruction of students in special lines. If this work is done as it should be, it must be done by colleges fitted for it, with courses, instructors, equipments and time for thorough work. A few years ago it would have been difficult to find such opportunities anywhere in the world, if we except a very few places. But it is different now. There are already a number of colleges in this country that are offering excellent opportunities for exactly the preparation that is needed for work of high character. All this contributes in more ways than one to the end of original study in some of the various branches of astronomy.

Then, the really important question is how is it possible to bring all these means of study, all these astronomers, professional and amateur, all these observatories and isolated instruments into useful and associated activity so as to bring out the most and the best results possible for the general advancement of astronomical knowledge. However desirable it may be to have many changes in the existing order of things, it is not possible to bring it all about in a single year. No one will suggest or endorse this. But it is true that something useful to astronomy can be done. In view of the true scientific spirit of the times it seems as if something ought to be done.

As a first step towards arousing a broader and a more lively interest in work going on by the professional astronomer, it may be suggested that the whole field ought to be better understood by the individual workers in the different parts of it. This might be done if astronomers were willing to make brief and regular reports to the astronomical journals of different countries, or even to one, if to report to more would be irksome. This publication has several times suggested this point, and, as often, offered to publish such accounts of their work regularly, as astronomers were willing to furnish. But only limited response came in consequence of it. The reason may be that most of the professional workers are not in the habit of this thing, and neglect it; or they are too busy and have no time to give to it. If either supposition is true, it is to be regretted. However, we are of the opinion that if a suitable leaflet or blank should be prepared and sent to astronomers generally, soliciting such items of news, facts and notes concerning individual work, discovery, theory or plan, that something useful would come of it. This will be undertaken soon, and suggestions concerning it from any source, will be thankfully received. We have no prizes to offer in this direction. It would doubtless greatly aid the enterprise if we had. That which is done in respect to prizes for useful comet work, as offered in a recent number of *The Astronomical Journal* is an excellent thing. It is producing good results in some quarters already. The *Journal* will doubtless, have all the comet matter it can take care of in the future, and cometary astronomy will be fostered generously. It is to be hoped that many other generous persons will recognize a like need in the proper study, classification and records of the minor planets. This theme has grown so large that it is a burden to the ordinary observer to keep track of it. A single illustration will show this. In attempting to account for the origin of the Holmes' comet after its orbit had been determined, the thought was suggested by two astronomers independently, that its sudden appearance may have been caused by the collision of two asteroids. As shown elsewhere in this issue a reasonable test of this hypothesis would be found in a somewhat critical examination of many of the orbits of the asteroid belt, with the aid of some important facts about them all. The present knowledge of the orbits, motions and places of the minor planets is not so complete or so well arranged and stated, as to make it an easy task to obtain the needed data for the study of this interesting question. This is saying nothing against that model work in this field which has been done by Professor Daniel Kirkwood. Indeed, it is such work as his with that of some others in Europe that has opened the door of possibility in this direction, and shown what may be done individually and from personal interest in a given theme. Now, if means and coöperation may be secured to put such needful work forward, und systematize it, knowledge of the theme itself and others related to it will certainly be improved. What is said of this particular field, may also, as well be said of many others. The general thought is systematic and associated work, with suitable endowment for it. There are competent scholars enough, instruments are not wanting, the desire, on the part of many, to do some useful work in astronomy was never greater. If, now, the year 1893 should bring about some needed changes in regard to these important suggestions, the advantages gained would richly repay all possible judicious outlay of money and energy to secure them.

THE STAR OF BETHLEHEM.*

LEWIS SWIFT.

I have read with great interest, as published in the *Astronomical Journal* of Nov. 26, Prof. Stockwell's "Supplement to Recent Contributions to Chronology and Eclipses." It shows much research and mathematical computation, and appears to add to our scanty knowledge of ancient chronology not only, but to settle many disputed points as well, but the concluding portion of the article relative to the star seen by the Wise Men in the east, though interesting and ingenious, is, in my opinion, untenable.

He proves from mathematical calculations that B. C. 6, there occurred on May 8 of that, year, a close conjunction of the planets Venus and Jupiter (yet 32′ asunder at their nearest approach), and, therefore, infers that this was the phenomenon which was seen of the Magi. He emphasizes the fact that the conjunction took place in the eastern morning sky which to his mind, harmonizes with the scriptural account, "For we have seen his star in the east." But this interpretation of the passage is strained and one it will not bear. Its meaning is simply this: that while they, themselves, were in the east they saw the star, not that the star was to the east of them. It is as if a person from Georgia who, while in this latitude, should witness an auroral display, and should assert that he had seen the same phenomenon in the south, not intending to convey the idea that the aurora was observed in the southern sky, but that he, the spectator, was stationed in the south. Or, again a man writing from, say, Oregon, a description of the geysers in the National Park might declare them the greatest wonder in the west, and yet he certainly would not be held to indicate that the National Park lay to the west of him.

Considering the star as of celestial origin, it is self evident that whether a conjunction of two planets, a bright comet, or the sudden appearance of a temporary star like that of 1572, as some contend, the body must have presented the same aspect at Jerusalem as in the east, which was not the case, or the troubled queries of Herod, who inquired diligently of the Wise Men what time the star appeared, would have remained unasked. Though all Jerusalem was troubled at the announcement, it is evident that no unusual celestial phenomenon was witnessed.

Again, the Magi were, doubtless, aged men who must many

* Communicated by the author.

times have beheld a conjunction of bright planets as well as the apparition of a brilliant comet, and so common an event as either would hardly have induced them to undertake so long a journey with the dubious prospect, from so ordinary an omen, of finding the promised Messiah.

According to Professor Stockwell the two planets were at their nearest approach over a half a degree apart, and of course, appeared as two separate stars, which fact is at variance with their statement, for they saw but one.

That this conjunction was supernatural, or, that the birth of the Savior was deferred until this celestial phenomenon occurred, are both assumptions too unreasonable to be accepted.

Taking into consideration that the Bible makes mention of only three kinds of heavenly bodies, viz.: Sun, Moon and stars, and that every unusual light, celestial or mundane, was called a star, I feel justified in emphatically asserting that what the Wise Men saw was not a star at all but a supernatural light which, quite likely, appeared in their own dwellings or, at least, at their dwelling places, and was not again visible until their arrival near Bethlehem when it re-appeared and "went before them till it came and stood over where the young child was."

As Venus was approaching superior conjunction with the Sun, it is plain that another with Jupiter could not occur, and, hence, the question arises, if the "star" they saw while in the east was a conjunction of Venus and Jupiter, what one was observed on nearing Bethlehem? The Bible declares it to have been the same star, but as several days or weeks were spent in journeying to the place of the Nativity, and as Venus was moving rapidly away from and was, probably, by the time of their arrival at Bethlehem, from ten to twenty degrees east of Jupiter, it could not possibly have been the same conjunction.

A star proper cannot by any possibility go before and guide a person to any particular house, any more than it can indicate a certain branch of a solitary tree.

Taking into consideration all the circumstances connected with this much discussed question, I am strongly of the opinion that, though of Divine origin, the phenomenon seen of the Wise Men was wholly terrestial and local. The theory of Professor Stockwell robs the extraordinary event of all supernaturalism, not only, but antedates the generally received time of the Saviour's birth by two years, or more than a year before the angel's annunciation.

WARNER OBSERVATORY,
Rochester, N. Y., Jan. 3, 1893.

THE ABSORPTION OF LIGHT IN SPACE.*

W. H. S. MONCK.

The problem whether any appreciable quantity of light is absorbed in traversing space has often been mooted without receiving satisfactory answer. It seems clear indeed either that there is such an absorption, or that there is a gradual thinning out of the stars—at least of luminous stars—as we proceed outwards from the Sun. For otherwise, the entire sky would glow with at least the brilliancy of the full Moon. And this conclusion is supported by other reasons. Taking the light-ratio of 2.512 to 1 for one magnitude, the stars of any given magnitude would be nearly four times as numerous as those of the magnitude next below it, assuming that the average distribution was uniform and that no light was lost in transmission. But so far as photometric measurements have extended, the proportion is always less than this. Three to one would be nearer the mark than four to one and would probably be too high also. A loss of light in transmission affords perhaps the most satisfactory explanation of this difference.

It recently occurred to me that a comparison of the proper motions of the stars of different magnitudes might lead to a solution of the problem. Assuming the average velocity of the stars to be the same at all distances from us, their average proper motions would vary inversely as the distance. Supposing then, that a difference of one magnitude corresponds to a ratio of 2.512 to 1 in the amount of light, it corresponds to a ratio of 1.585 to 1 (the square root of the foregoing) in the average distances, or pretty nearly to a ratio of 1.25 to 1 for a half-magnitude. The average proper motions should diminish in this ratio for each half-magnitude assuming that there is no loss of light. But on the assumption of a loss of light in traversing space, the light of a distant star will diminish more rapidly than in the ratio of the inverse square of the distance. The distance-ratio, corresponding to a difference of half a magnitude, will, therefore, be less than 1.25 to 1, and the average proper motion will, of course, be diminished in less than that ratio. It seemed, therefore, that there was a prospect of deciding the question by a comparison of the proper motions of a number of stars whose photometric magnitudes had been determined, and ascertaining the rate at which these proper motions diminished for each half-magnitude.

* Communicated by the author.

I had already noticed that there were great differences in the proper motions of stars of the same magnitude with different kinds of spectra, and I therefore resolved to take the results separately for the Sirian stars (A and B of the *Draper Catalogue*, the Arcturians (H, I and K of the same Catalogue) and the Capellans (E and F). I took up the Pulkova Catalogue of Proper Motions and ascertained, in as many cases as possible, the spectrum of the star together with its photometric magnitude (from the *Harvard Photometry*). The number of stars between 4.0 and 6.5 seemed large enough to warrant taking the results separately for each half-magnitude; though I suspect that those for magnitudes 6.0 to 6.5 are too high, many stars having been inserted in this part of the Pulkova Catalogue on account of their large proper motions where their compeers with smaller proper motions are omitted. I examined the proper motions in declination only, as those in R. A., which would be more troublesome to tabulate, probably followed the same law. To avoid the effect of a few stars with abnormally large proper motion, I took as the mean the point where the number of stars with greater and less proper motion was equal. Lastly, as Auwers' Catalogue contains a larger number of bright stars than the Pulkova Catalogue, I carried the table back to magnitude 3.0 by consulting it—omitting, however, the division 3.0 to 3.5 in the case of the Capellan stars because I had only 5 stars of this class to deal with. The following are my results:

SIRIAN STARS.

Magnitude	Stars	Av. Motion in N. P. D. ″	Magnitude	Stars	Av. Motion in N. P. D. ″
3.0 to 3.5	29	0.0345	5.0 to 5.5	283	0.018
3.5 to 4.0	46	0 0255	5.5 to 6.0	236	0.018
4.0 to 4.5	57	0.021	6.0 to 6.5	72	0.021
4.5 to 5.0	149	0.019			

ARCTURIAN STARS.

Magnitude	Stars	Av. Motion in N. P. D. ″	Magnitude	Stars	Av. Motion in N. P. D. ″
3.0 to 3.5	24	0.036	5.0 to 5.5	158	0.0255
3.5 to 4.0	46	0.0545	5.5 to 6.0	150	0.025
4.0 to 4.5	46	0.031	6.0 to 6.5	45	0.025
4.5 to 5.0	91	0.026			

CAPELLAN STARS.

Magnitude	Stars	Av. Motion in N. P. D. ″	Magnitude	Stars	Av. Motion in N. P. D. ″
3 5 to 4.0	13	0.154	5.0 to 5.5	75	0.067
4.0 to 4 5	14	0.109	5.5 to 6 0	82	0.047
4.5 to 5.0	41	0.044	6.0 to 6.5	32	0.062

These results are hardly satisfactory. With the fainter Sirian and Arcturian stars indeed, the ratio of decrease is very decidedly less than 1.25 to 1 for each half magnitude, but the difference seems too great to be accounted for by the loss of light in space. The average motion in these cases is very small and I suspect that errors of observation and computation contribute largely to the result. Where the quantities of motion are larger, as in the Capellan stars and the brighter Sirians and Arcturians, there is considerable fluctuation in the results, but I do not think it can be said that taking them all round, the average decline is less than 1.25 to 1 for each half magnitude. The data which I have examined would thus appear insufficient to decide the question. It may be worth while, however, to give another table setting out the results obtained for all the stars including some whose spectra are not given or are not reducible to any of the foregoing heads. In this table those between magnitudes 3 and 4 are taken from Auwers' Catalogue and between 4 and 6.5 from the Pulkova Catalogue.

AVERAGE.

Magnitude	Stars	Av. Motion in N. P. D. ″	Magnitude	Stars	Av. Motion in N. P. D. ″
3.0 to 3.5	65	0.032	5.0 to 5.5	548	0.022
3.5 to 4.0	124	0.044	5.5 to 6.0	503	0.022
4.0 to 4.5	121	0.025	6.0 to 6.5	173	0.021
4.5 to 5.0	305	0.023			

I do not think the absorption of light in space can be great enough to account for this extremely slow rate of diminution. When the other causes are discovered, we shall be better able to judge of their sufficiency without calling in the aid of this absorption. The problem may perhaps be approached in a different way, viz., by ascertaining the number of stars with different amounts of proper motion and finding how the number of stars increases as the motion diminishes. But here too, I fear our Catalogues are not, at present, complete and accurate enough to afford decisive results.

PHOTOGRAPHING MINOR PLANETS.*

DR. MAX WOLF.

In December 1886, Dr. Isaac Roberts first succeeding in photographing with his telescope the minor planet Sappho, estimated to be of the 11th magnitude. The planet described a short trail

* From the *Journal of the British Astronomical Association*, Dec. 17, 1892.

on the plate amongst the stars near the place of the ephemeris; and from the plate the correction of the ephemeris was immediately obtained.

The difficulty in detecting a minor planet, amongst the enormous number of faint stars, by eye-observation is very great, because it is only by its movement that the planet can be discerned. The observer must, therefore, make a diagram of the region in which he supposes the planet to be. After a time, on comparing the diagram star by star with the sky, he finds that one star—the planet he sought for—has moved, always supposing, that is to say, that he has examined its right place, and not, by mistake, a neighboring but inaccurate position. Photography holds out two great advantages over that method; it gives a larger field, while the planet marks its trail and therefore immediately distinguishes itself from the surrounding stars.

I commenced photographing minor planets in August 1890, using both a telescope lens of 16.2cm. aperture and 262cm. focal length, and an aplanatic lens of 6cm. aperture and 44cm. focal length. I was seeking for several lost asteroids at the time during several nights, and used ten plates with long exposures. I had no success because I could not employ suitable lenses, the focal length of the first employed being too long, and the aperture of the second too small. To photograph minor planets both a large field and a marked brightness of image is required. For photographing nebulæ the brightness* has as factor the quantity $\frac{D}{F^2}$, where D is the diameter of the object-glass and F the focal length of the lens employed. But it is quite a different thing with asteroids, of which the area is a "point." The brightness of the image on the plate would be the same as from a fixed star of equal intensity. It would have as factor the quantity D^2, if we neglect for simplicity's sake the small influence of the focal length. But the asteroids are moving and are drawing a trail amongst the stars on the plate. This trail becomes longer when using a lens of longer focus, the intensity of a planetary trail drawn by a longer focus lens is diminished. It therefore results that the brightness has as factor the quantity $\frac{D}{F^2}$.

To photograph asteroids, therefore, we need a lens with an aperture as great as possible, with a focal length as short as possible, and giving a large field; as for instance, a large portrait lens.

From this point of view I recommenced the photography of

* *Journal*, British Astronomical Association, 1891, p. 252.

minor planets in November 1891, using my 5¼-inch Kranz aplanatic lens. After some experiments in focussing the plate, I succeeded in getting on my plate, on the evening of December 22, the first *new* minor planet discovered by means of photography. This is No. 323, "Brucia." On the same plate I found the lost planet 275, "Sapientia," both of the 12th magnitude.

For the identification of this planet, and also for invaluable assistance in calculation, I am indebted to Herr Berberich, of Berlin, the well-known "surveyor" of the orbits of asteroids.

Since then I have photographed a great number of old and new minor planets. From 1891, November 28, till 1892, April 25, I got 125 different positions of 58 different minor planets; 17 of which were new discoveries.

For the most part the positions were roughly taken from the Argelander charts, but a great number were measured. This measurement is quite simple. A microscope with a long focus object lens and supplied with a filar micrometer in the eye-piece is alone required. The distance of the middle of the planetary trail from several known stars on the plate is measured. The distances give, by a simple trigonometric example, the differences in R. A. and in N. P. D. from one of the known stars. The accuracy gained by this simple arrangement is within a fraction of one second of arc; the measures are therefore equivalent to eye observations.

Since May 1892, besides many known planets, several lost, and several new planets have been discovered by my photographic lenses, and it has been found necessary since August, to introduce a new method of reckoning the newly discovered asteroids.

I hope the fact will be of interest for your members that the new planet "1892 C," was discovered by my friend, Mr. A. Staus, who is a member of your Association.

The success already obtained proves that it is easy to find all the hitherto lost minor planets, and to arrange for a simple and sure watch over all the known asteroids, working with lenses of large field and great light-grasping power, and by means of the self-registering action of the planetary trails on the photographic plates.

The work is very straining and fatiguing, because I have to expose each plate for two hours, controlling without intermission the driving clock by the guiding telescope. But this is only caused by the want of means to procure a larger lens and a better clock, and unfortunately there is little hope of obtaining them in Germany.

HEIDELBERG OBSERVATORY, 1892, September.

THE DOUBLE STAR Σ 2145.*

H. C. WILSON.

On the night of June 8, 1892, while taking a measure of the double star Σ 2145, I noticed that the larger component was itself a very close double, and estimated the distance at $0''.3$. My measures gave position angle $44^\circ.7$; distance $0''.52$. I have reason to suspect, however, that for several nights during the summer a little knot on one of the micrometer threads caused them to catch a little as they passed so that I could measure nothing less than $0''.5$. The night was a very fine one, bearing a power of 1,000 readily, and the stars were clearly separated. Several other close doubles were measured on the same night, among them OΣ 309, which is described in my notes having "beautiful images; no rings; distinctly separated." The power used in all the measurements was about 500. On subsequent nights, when the seeing was fair the close components of Σ 2145 could not be distinctly separated but on every occasion the elongation was easily noticed.

I speak of this star because it is likely to prove an interesting binary and because its discovery indicates something of the excellent defining power of the 16-inch refractor which was made for Goodsell Observatory by Messrs. Hastings and Brashear. Both Professor Hough and Mr. Burnham on different occasions, not, however, under best atmospheric conditions, tried the star with the 18-inch refractor of Dearborn Observatory and failed to detect duplicity or elongation.

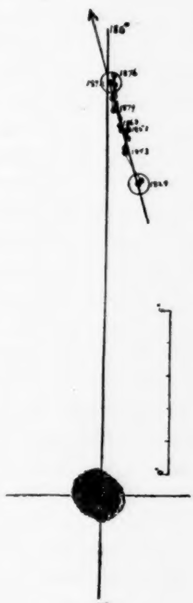
At Mr. Burnham's request Mr. Barnard looked up the star with the 36-inch refractor at Lick Observatory and pronounced it a fine double. He has recently sent me his measurements, which I give below.

The Struve pair has been measured by several observers since 1829 and its distance has increased $3''$, evidently from proper motion. It seems from this that the new pair must be a binary and that its distance has for the last 60 years been very small, otherwise some of the observers must have detected it. The following are all the measures which I have at hand. Some of the earlier measures were kindly furnished me by Mr. Burnham:

* Communicated by the author.

Measures of the Σ Pair.

Epoch.	Pos. Angle. °	Distance. ″	No. of Nights.	Observer.
1829.68	174.4	9.72	1	Struve.
32.30	174.1	9.87	1	"
43.65	177.0	10.61	3	Mädler
45.17	177.2	10.74	4	"
51.69	176.9	11.29	..	"
52.33	178.0	11.26	..	"
54.78	176.8	11.12	..	"
58.72	178.8	......	..	"
63.41	178.2	11.32	..	Dembowski
76.47	178.8	12.93	1	Wilson and Seabroke
77.45	179.1	12.64	1	Fletcher
79.24	178.6	12.25	3	Schiaparelli
79.37	177.9	11.89	2	Howe (Cincinnati 5)
92.55	179.5	12.74	3	Wilson



Measures of the New Pair by H. C. Wilson.

Epoch.	Pos. Angle. °	Distance. ″	Magnitude.	
1892.437	44.7	0.52	8.0	8.5
.593	39.1	0.3 ± est.	8.5	9.0
.596	43.2	0.3 ± est.	8.0	9.0
.609	48.9	0.67	8.5	9.5
.623	45.4	0.53	8.5	10.0
.648	51.1	0.42	8.5	10.0
1892.584	45.4	0.46	8.3	9.3

Measures by Mr. Barnard.

1892.809	49.9	0.4 ± est.	nearly equal.
.814	50.2	0.40	
.847	49.0	0.43	
1892.823	49.7	0.41	

Σ 2145.

R. A. 17^h 12^m; Decl. 26° 43′.

WORK FOR LARGE TELESCOPES.*

EDWARD C. PICKERING.

A wide popular interest is now felt in telescopes of the largest size. The general public has no doubt an inordinate idea of what they should show. Some persons, however, considering the great cost and supposed limited field of work of a large telescope, maintain that results of greater value might be reached by a different expenditure of money. Undoubtedly, in the United States, the capital invested in large telescopes is out of all proportion to the income available for keeping them at work, and perhaps on this account the results attained are less than might be expected. As difficulty is often found in providing suitable work for a large telescope, it may be worth while to enumerate some of the researches in which such an instrument might secure results which could not be obtained with a smaller instrument. As it is not easy to decide whether more useful results could de obtained visually or photographically, it would be a great mistake to make the instrument of such a form that it could not be used in both ways. This is readily done by making the front lens reversible, with surfaces of unequal curvature. The additional expense is slight, and the objection that the photographic field is diminished owing to the necessary separation of the lenses, is not important when the focal length is very great, since the available field is then larger than can be conveniently covered by a single photographic plate. The only large lens as yet used in this way has an aperture of thirteen inches, and is now at the Harvard station in Peru. The photographic results in California, and the visual results in Peru indicate that when employed in either way its definition is unsurpassed. The focal length of the instrument here proposed should be as great as possible. The Bruce photographic telescope will have such advantages over other instruments when a relatively short focal length is desired that competition with it in this respect would generally be undesirable. The focal length is likely to be limited by the mechanical difficulties and the expense of constructing a suitable dome. The optical difficulties diminish with the increase of focal length.

A telescope of the largest size, constructed so that it could be used either visually or photographically, and mounted in a location where the atmospheric conditions were favorable could be usefully employed on either of the twenty researches enumerated

* Communicated by the author.

below. A portion of them have already been undertaken with the 15 and 13-inch telescopes at the Harvard stations at Cambridge and Arequipa. They should be extended to stars beyond the reach of the Harvard instruments.

1. Micrometric measures of close double stars. The great focal length should render the errors extremely small.

2. Micrometric measures of faint satellites.

3. Positions of comets only when beyond the reach of smaller instruments.

4. Diameter of planets, satellites and bright asteroids.

5. Approach and motion of all known gaseous nebulæ by visual observations of their spectra, as has been done in certain cases at the Lick Observatory.

6. Photometric measures of the light of faint stars selected as standards, including faint comparison stars for variables, stars selected from clusters, standards proposed by the Committee of the American Association (Proc. XXXIV, 1). The measures may be made with the aid of a wedge, a Zöllner photometer or an auxiliary telescope (Harvard Annals, XI, Part II, XIII, Part II).

7. Relative brightness of components of double stars (Harvard Annals, XI, Part I.

8. Photometric measures of Jupiter's satellites, while undergoing eclipse.

9. Measures of the intensity of the various portions of the brightest nebulæ, and the central portions of the fainter nebulæ. At Cambridge this is done by comparing with the image of a known star in an auxiliary telescope thrown out of focus by a measured amount. If the nebula has a stellar nucleus throw it also out of focus by a known amount. This gives the mean brightness of the vicinity of the nucleus. Apply the same method to comets. Measure clusters in the same way, throwing them out of focus until the separate stars are indistinguishable. This seems to indicate the density of the cluster, or ratio of the mean diameters of the stars to their distances apart.

10. Observations by Argelander's method of variables when too faint to be observed elsewhere.

11. Examination of all stars brighter than a given magnitude for faint and close companions.

12. Study of clusters in connection with photographs, to determine the number of stars in portions not resolved in the phophotographs (see No. 16).

13. Study of the surfaces of the Moon, planets and satellites with very high powers. This can be done usefully only if the location is such that the air is extremely steady.

14. Search for faint planetary nebulæ, bright line stars (near central line of the Milky Way) and stars of the fourth type. Use a direct-vision prism or a prism of small angle near the focus with an eye-piece of very low power.

15. Study of the spectra of known nebulæ when large with a slit spectroscope, when small with the apparatus described in No. 14. Of the nine or ten thousand known nebulæ and clusters the spectra of about a hundred only are known to be gaseous and of a few hundred more to be continuous. The composition of all the rest is unknown. The spectra of some clusters may be peculiar.

16. Photograph doubles and all clusters coarse enough to be resolved, and measure the relative positions and brightness of the components.

17. Photograph Jupiter's satellites while undergoing eclipse. Move the plate in declination every 5 or 10 seconds thus obtaining a series of images.

18. Photograph the Moon and planets enlarging the image in the telescope by means of an eye-piece especially constructed for the purpose.

19. Measure the approach and recession of the stars from photographs of their spectra as has been done at the Potsdam Observatory.

20. Photograph the spectra of the coarse clusters and doubles with the apparatus described in No. 14. Short spectra with poor definition are thus obtained, but very faint stars can be photographed and the separation due to the great focal length will show to which type they belong, even if they are very closely crowded together.

The last five researches will be excluded if the telescope cannot be used photographically. In this case, something might still be done by using plates stained with erythosin. Great steadiness of the air, such as seldom occurs at existing Observatories, is requisite for Nos. 1, 4, 11, 12, 13 and 18. For Nos. 3, 6, 9, 10, 14 and 15, the sky must be dark and no electric lights near.

HARVARD COLLEGE OBSERVATORY,
Cambridge, Mass., Jan. 11, 1893.

THE ASTRO-PHOTOGRAPHIC CHART.*

HAROLD JACOBY.

The general purpose of this important international enterprise is well known; but now that the making of the negatives has actually begun, it may be of interest to give a brief sketch of the present condition of the work, as shown by the action taken at the more recent committee meetings. Some of the resolutions previously adopted have since been repealed or amended; others, though not formally repealed, have failed to be carried into execution. It will thus be seen that there is now a tendency to allow a certain flexibility in the interpretation of the resolutions. Whenever possible, individual opinion is to direct individual effort, and absolute uniformity in the work of different observatories is to be insisted upon in matters of fundamental importance only. There does not seem to be any probability that the enterprise will fail, either on account of differences of opinion, or from an attempt to attain too high a degree of accuracy or uniformity.

Selecting from among the many details recently published concerning the work, it is interesting to note the way in which the plates are to be distributed upon the sky. It will be remembered that the photographic refractors are to have an aperture of $0^{m}.33$, and a focal length of about $3^{m}.43$. Thus a minute of arc upon the sky will correspond to about 1^{mm} on the plates. The latter are to be 160^{mm} square, but the "effective field" is to be taken as only two degrees square. Now, neighboring plates are to overlap in declination by at least half their diameter, so that a star situated at the center of one plate will also be found near one corner of the effective field of the next plate. In order to accomplish this in the simplest way, the plates are to be exposed so that their centers will lie upon successive parallels of declination one degree apart. The whole sky will thus be covered by successive bands of plates. Now the center of the first plate for bands of even declination will correspond to $0^{h}\ 0^{m}$ of right ascension. For the bands of odd declination, the first plate will be centered upon a point whose right ascension is approximately the mean of the right ascensions belonging to the first and second plates of the neighboring band. This arrangement will be easily understood from the accompanying table. Near the equator it will be sufficient to have the other plates of each band

* Communicated by the author.

follow at intervals of 8^m of right ascension. But as the declination increases, the right ascensions of contiguous plates will differ by more than 8^m, until at last, the polar band will contain one plate only. The arrangement finally decided upon is exhibited in the following table:

TABLE OF ARRANGEMENT OF PLATES.

Declination of Band.	R. A. of First Plate of Band Even Decl.		Odd Decl.		Interval R. A. Consecutive Centres.	No of Plates in 1 Band.	Total No. of Plates.
° °	h	m	h	m	m		
0 to 27	0	0	0	4	8	180	4950
28 to 36	0	0	0	4	9	160	1440
37 to 48	0	0	0	5	10	144	1728
49 to 59	0	0	0	6	12	120	1320
60 to 63	0	0	0	8	16	90	360
64 to 66	0	0	0	9	18	80	240
67 to 70	0	0	0	10	20	72	288
71 to 74	0	0	0	12	24	60	240
75 to 78	0	0	0	15	30	48	192
79 to 82	0	0	0	20	40	36	144
83 to 85	0	0	0	30	60	24	72
86 to 87	0	0	0	45	90	16	32
88	0	0			120	12	12
89			1	30	180	8	8
90						1	1
Total No. of Plates for one Hemisphere							11027

The numbers in the fifth column of this table are obtained by dividing 1440 (the number of minutes in 24^h) by the interval of successive centres as given in column 4. The last column is obtained by multiplying the number of plates in one band (as given in the fifth column) by the number of bands (as indicated in the first column). But the plates whose centres are at 0° declination are credited half to each hemisphere. Thus, for instance, from 37° to 48° there are 12 bands of 144 plates each, or 1728 plates in all. Now suppose we wish to know what plates will contain a star in R. A. $0^h\ 47^m$, Decl. 39° 40′. The above table shows that it will be on the 6th plate of the 40° band and the 5th plate of the 39° band. For in accordance with the explanation already given, the bands of odd declination have the first plate at $0^h\ 5^m$ right ascension for declinations between 37° and 48°.

Of course, in order to make certain that the plate is really exposed to the proper point on the sky, it is necessary for the astronomer to bisect a certain known guide-star, with the micrometer of the guide-telescope attached to the photographic equatorial. The selection of these guide-stars from the existing star catalogues has caused considerable trouble. It was at first intended that they should not be further than 22′ from the centre of the plate, and the lists have been drawn up accordingly. But in order to accomplish this, it has been found necessary to admit many stars of less than the 9th magnitude. It has, therefore, been finally decided that each astronomer may select a fresh guide-star not more than 40′ from the center, whenever the star set down in the official list shall, in his judgment, appear too faint for easy observation in a bright field.

It is perhaps unnecessary to refer to the much discussed question of the réseau. This consists of a plate of silvered glass, upon which two series of parallel lines are ruled so as to divide the whole surface into small squares 5^{mm} by 5^{mm}. Before the plates are exposed to the sky, they are covered with the réseau plate, and the whole exposed for a short time to parallel light. In this way a latent image of the réseau is impressed upon the plate, and will appear during development. It is plain that by afterwards measuring the star's positions with respect to the nearest réseau lines, we can secure results that are independent of any possible deformation of the film during development. It has been decided that the réseau shall be applied to all plates, but the method of application is left to the individual judgment of each astronomer. With regard to the focussing of the plates, no definite decision has been reached: but it is probable that the focal plane will be selected so as to give the best images for a point about 40′ from the centre of the plate. The orientation of the plates is to be such that one set of lines of the réseau will be parallel to the equator. For plates whose declination is greater than 65°, the orientation is to be referred to the equator of 1900; other plates will be oriented according to the apparent equator of the day.

The question of duration of exposure, in relation to the photographic magnitudes of the stars has given rise to much discussion. It will be remembered that the series of plates destined for the formation of the chart are to contain all stars to the 14th magnitude, while the series of shorter exposure, from whose accurate measurement a catalogue is to be constructed, must show all stars to the 11th magnitude. It seems likely that the discussion of this question will end in the simple practical expedient of making a trial negative each night of some type-region of the sky. Now, if the magnitudes of the stars in the type-region have been previously adopted as known, it will be easy to find out the exposure necessary on any particular night to insure the presence on the negatives of all stars of the desired magnitude. This process will probably lead to a considerable degree of uniformity in the results from the several observatories. And after all, the astro-photographic project does not aim too high. It is intended to secure what astronomers have always sought for;—observational results of the highest *attainable* accuracy. In order to prevent the occurrence of "false stars," such as would be caused by specks in the film, it may be found necessary to have double or triple images on the chart plates. This question has not been definitely decided, but it seems probable that the plates of even declination will have single images, while the series of odd declination, to be made later, will have triple images.

With regard to the measurement of the catalogue plates, each observatory is to begin as soon as convenient. The measures need not necessarily be made at the observatory itself, but the plates may be sent for measurement to some other observatory, or to some "bureau of measurement." The uncorrected results of these measures are to be published by the several observatories. The final reduction will be undertaken by the permanent committee, as soon as the question of standard stars can be settled. It is obvious that in the final rigorous computations the orientation and scale value must always be obtained from measures of the images of several standard stars impressed on the plate. For the whole heavens, it would thus be necessary to know accurately the positions of some sixty or seventy thousand stars. Now the existing star catalogues are not sufficient to furnish these positions. It seemed, therefore, as though the final reduction of the catalogue plates would have to be deferred until the requisite number of stars could be determined in the meridian. Fortunately, a plan has been proposed by M. Loewy which will, in all probability, do away with this formidable difficulty. This plan consists in taking advantage of the circumstance that the plates overlap in declination by at least half their diameters. Indeed, it is obvious that by means of the stars common to two overlapping plates, we can, as it were, connect the two together, just as though they were merely parts of a single plate. For this purpose it is, of course, not necessary that the stars common to the two plates should be previously well determined. Now as the arrangement of the successive bands is such that every plate has four others overlapping, it is clear that the above process will be equivalent to giving us a space of four plates; or sixteen, instead of four, square degrees, wherein to look for standard stars. In so large a space, the existing catalogues will almost always furnish a sufficient number. It is difficult to foresee any reason why this plan of M. Loewy's should fail: the results of a practical trial will doubtless soon be published, and will, it is hoped, set this important question definitely at rest.

In conclusion, it may be of interest to set down the names of the several Observatories taking part in the work, together with the zones assigned to each for observation.

TABLE SHOWING DISTRIBUTION OF WORK.

Observatory.	Latitude. ° ′	Decl. of Zone. ° °	Zenith Distance. ° ′ ° ′	No. of Plates.
Greenwich	+ 51 29	+ 90 to + 65	− 13 31 to − 38 31	1149
Rome	+ 41 54	+ 64 to + 55	− 13 6 to − 22 6	1040
Catania	+ 37 30	+ 54 to + 47	− 9 30 to − 16 30	1008
Helsingfors	+ 60 9	+ 46 to + 40	+ 14 9 to + 20 9	1008
Potsdam	+ 52 23	+ 39 to + 32	+ 13 23 to + 20 23	1232
Oxford	+ 51 46	+ 31 to + 25	+ 20 46 to + 20 46	1180
Paris	+ 48 50	+ 24 to + 18	+ 24 50 to + 30 50	1260
Bordeaux	+ 44 50	+ 17 to + 11	+ 27 50 to + 33 50	1260
Toulouse	+ 43 37	+ 10 to + 5	+ 33 37 to + 38 37	1080
Algiers	+ 36 48	+ 4 to − 2	+ 32 48 to + 38 48	1260
San Fernando	+ 36 28	− 3 to − 9	+ 39 28 to + 45 28	1260
Tacubaya	+ 19 24	− 10 to − 16	+ 29 24 to + 35 24	1260
Santiago	− 33 27	− 17 to − 23	− 10 27 to − 16 27	1260
La Plata	− 34 35	− 24 to − 31	− 3 55 to − 10 55	1360
Rio Janeiro	− 22 54	− 32 to − 40	+ 9 6 to + 17 6	1376
Capetown	− 33 56	− 41 to − 51	+ 7 4 to + 17 4	1512
Sydney	− 33 52	− 52 to − 64	+ 18 8 to + 30 8	1400
Melbourne	− 37 50	− 65 to − 90	+ 27 10 to + 52 10	1149
Total number of plates				22054

THE COMETS OF 1892.*

H. C. WILSON.

Seven comets were discovered during 1892, all remaining visible until nearly the close of the year. Five of them are still visible with large telescopes. Comet 1890 II was rediscovered at Nice, 1892, Jan. 6, but no further observations have been reported. Wolf's periodic comet, found by Barnard May 3, 1891, and the Temple-Swift periodic comet, found by Barnard Sept. 27, 1891, were followed into the first months of 1892. Three periodic comets were due this year: Brooks 1886 IV, Tempel$_1$, and Winnecke. The first two were not found.

COMET *a* 1892.—Was discovered by Lewis Swift at Rochester,

* Communicated by the author.

N. Y., on the morning of March 7. It was very bright and easily visible to the naked eye. At the time of its perihelion passage the tail of the comet was visible for 12° or 15° from the nucleus. Some beautiful photographs taken by Mr. Barnard at this time reveal interesting features in the structure of the comet which were not visible to the eye. Some of these photographs have been reproduced in *Knowledge*, Dec. 1892. The spectrum of this comet was observed by Campbell at Lick Observatory and found to be of the usual type, continuous for the nucleus and banded for the coma and tail. These observations were published in ASTRONOMY AND ASTRO-PHYSICS, Oct. 1892. The comet is still visible in large telescopes. With the 16-inch refractor of Goodsell Observatory on Jan. 12 it was faint, small and round, with a strong condensation in the center. It doubtless may be followed for another month yet. The orbit is very nearly a parabola. The elements calculated by Miss F. Gertrude Wentworth (*Astr. Jour.*, No. 273) represent the path of the comet quite well up to the present time.

COMET *b* 1892.—Winnecke's periodic comet was found with the 27-inch refractor at Vienna, March 18, within 4^s in R. A. and 10′ in Decl. of the place predicted by Dr. E. von Hærdtl (*Astr. Nach.*, No. 3062). In June and July it was quite a bright telescopic object. By the last of October it was again so faint as to be visible only in large telescopes.

COMET *c* 1892.—Discovered by W. F. Denning, at Bristol, Eng., March 18. It has all the time been a very faint comet but at last reports was still visible with a 10-inch reflector. The orbit is probably a parabola.

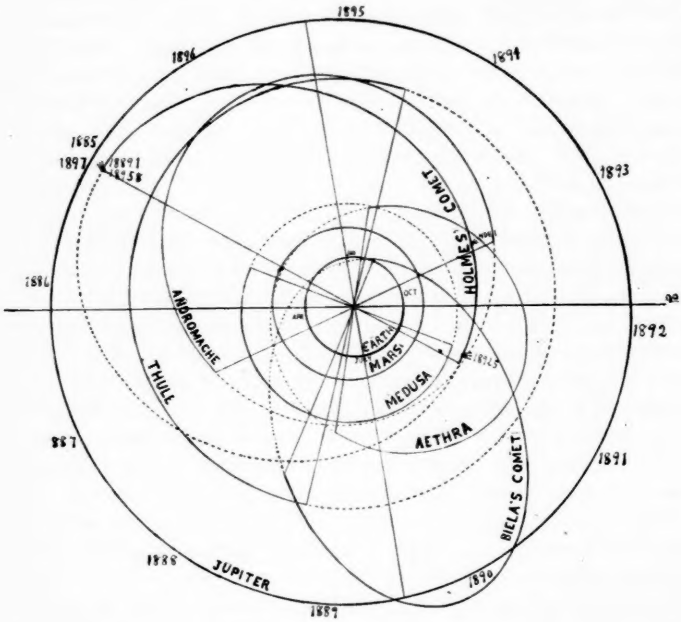
COMET *d* 1892.—Discovered by W. R. Brooks at Geneva, N. Y., Aug. 28. It was a bright telescopic comet with short tail. It increased quite rapidly in brightness reaching a maximum in December when the tail was visible to the naked eye, the length being about 5°. This comet is still visible but is too far south for observation in this latitude. The orbit is probably parabolic.

COMET *e* 1892.—Discovered on a photograph by Barnard Oct. 12. It is the first comet discovered by photography, and it is remarkable that a comet so faint visually should have been thus discovered. The comet very quickly faded away becoming invisible in the largest telescopes in a few weeks. The orbit is probably elliptic. Professor Krueger has obtained a period of 6.3 years. M. Schulhof has also computed elliptic elements, with a period of about 6 years, but the observations are too few to give any very certain results. M. Schulhof also calls attention to the similarity of these elements to those of Wolf's periodic comet. He suggests that the two have the same origin, are, in fact, parts of the same comet which separated at some time previous to 1885. In that year they were in the vicinity of Jupiter together and suffered violent perturbations by the planet. A relatively small difference in their epochs of passing peri-jove would be sufficient to produce the considerable difference in their inclinations and excentricities.

COMET *f* 1892.—Discovered by Edwin Holmes, in England, Nov. 6. So much has been said recently about this comet that it seems unnecessary to say more now; yet, for the sake of completeness of this article, a brief recapitulation ought to be given. The comet was so bright when discovered that it could be seen with the naked eye, and as it was in a region frequently examined by amateurs, only a few degrees from the great nebula of Andromeda, it seems remarkable that it was not discovered earlier, when theoretically it should have been brighter. Mr. Holmes says that he examined that region on Oct. 25 and observed nothing special.

Mr. Berberich, of Berlin, noticed that the comet was very near the Bielid meteor radiant and announced that possibly this might be Biela's comet, which has been lost sight of since 1852. As soon, however, as sufficient observations were obtained to permit the computation of an orbit, it was found that this comet was much farther away than Biela's and was receding from instead of approaching the Earth. The orbit is found to be a short ellipse, the period being about 6.9 years. The orbit is less excentric than that of any other known comet, and approaches more nearly to those of the asteroids. According to the elements of Professor Boss (*Astr. Jour.* No. 283), which represent the observations up to the present time very well, the aphelion distance is 5.12, less than that of Jupiter, and the perihelion 2.14, greater than the aphelion of Mars.

In the accompanying cut are given for comparison the orbits of Holmes' and Biela's comets and those of some of the asteroids and the planets, Earth, Mars and Jupiter. Thule (279) has the largest of the known asteroid orbits, Medusa (149) the smallest, Aethra (132) the most excentric. Aethra has the smallest perihelion distance and Andromache (175) the greatest aphelion distance. In drawing the diagram the inclinations of the orbits were neglected, so that they are shown in their true proportions though not in their true relation. The dotted portions lie below the ecliptic. If all the 350 and more asteroid orbits were to be platted in the same way, the space between Thule and Medusa would be so filled with intersecting ellipses that very little paper would be visible through the ink. A glance at the diagram shows that the orbit of Holmes' comet lies for the most part within the asteroid zone, but that it also approaches at aphelion so near to the orbit of Jupiter that it may be subject at times to violent perturbations. Running back with the period 6.91 years we find no close approach of the comet to Jupiter until the year 1861. The question then arises, why the comet has not been seen at some of the returns since that time. Its position would have been more favorable at each of those apparitions than at the present one.



ORBITS OF HOLMES' AND BIELA'S COMETS AND SOME OF THE MINOR PLANETS.

The unusual behavior of the comet in its rapid decrease of brightness and expansion of volume while receding from the Sun has also given rise to question as to the nature of its constitution. Its spectrum, too, distinguishes it from other comets, indicating that it shines principally by reflected sunlight. The spectrum, according to Mr. Campbell of the Lick Observatory, is continuous with perhaps traces of the usual cometary bands in the green and yellow (A. AND A. Jan. 1893). In view of these peculiarities Mr. Corrigan (A. AND A. Jan., 1893) proposes the theory that Holmes' comet had its origin in a collision of two asteroids a short time previous to Nov. 6, 1892. On another page in this number of ASTRONOMY AND ASTRO-PHYSICS he shows that none of the known asteroids can be components of the comet.

While this article was in preparation a change occurred in the comet which throws Mr. Corrigan's theory in doubt. For a month back the comet has been so exceedingly faint that it has been very difficult to determine its position micrometrically, even with large telescopes. On the night of Jan. 12 this was still true. On Jan. 16, however, the writer was astonished to find the nucleus and coma almost as bright as in November. The coma was less than 1′ in diameter but very dense, and the nucleus was as bright as an eighth magnitude star. Evidently some new commotion has taken place in the nucleus which it would perhaps be stretching the limits of probability to explain as the result of a new collision of asteroids. The same phenomenon was observed

Elements of the Comets of 1892.

	Synonym.	Discoverer.	Date of Discovery.	Perihelion Passage.	π	ω	Ω
				GR. M. T.	° ′ ″	° ′ ″	° ′ ″
a	1892 I...	Swift..........	March 7.....	April 6.66545	265 27 29.1	24 31 59.4	240 55 29.7
b	IV...	Spitaler......	March 18.....	June 30.90209	276 10 56.6	172 03 32.9	104 07 23.7
c	II...	Denning......	March 18.....	May 11.18321	22 44 16.0	129 18 34 4	253 25 41.6
d	VI...	Brooks........	Aug. 28.....	Dec. 28.0932	157 08 51.1	252 40 52.7	264 27 58.4
e	V...	Barnard......	Oct. 12.....	Dec. 11.0083	16 52 36.0	170 13 51.1	206 38 44.9
f	III...	Holmes........	Nov 6.....	June 12.6152	345 35 25.5	13 49 49.6	331 45 35.9
g	1893 I...	Brooks........	Nov. 19.....	Jan. '93 6.5270	270 54 11.0	85 15 05.4	185 39 05.6

	i	*e*	*q*	Computer.	Reference.
	° ′ ″				
a	38 42 45.9	1.000000	1.026966	Wentworth	A. J. 273
b	14 31 30.8	0.725988	0.886595	Von Hærdtl	A. N. 3112
c	84 42 04.3	1.000000	1.970693	Schorr	A. N. 3089
d	24 47 51.4	1.000000	0.976129	Ristenpart	A. N. 3131
e	31 12 28.1	0.581228	1.42912	Krueger	A. N 3129
f	20 48 00.0	0.411472	2.135982	Boss	A. J. 283
g	143 52 16.4	1.000000	1.294890	Maitre	A. J. 3838

by Palisa at Vienna, and by Hough at Evanston, Ill., on the same night. Professor Hough observed the comet on Jan. 14 and found it still faint, so that the change must have occurred between Jan. 14 and 16.

Comet *g* 1892.—Discovered on the morning of Nov. 20 by W. R. Brooks at Geneva, N. Y. It was rather bright and had considerable condensation, with which the coma was not quite concentric. It has increased in brightness up to the present time and now has a tail about a degree in length. It will be visible for some months yet.

THE NEGLECTED FIELD OF FUNDAMENTAL ASTRONOMY.*

J. R. EASTMAN.

The limits of this address would scarcely suffice simply to name the problems now under discussion by the more modern methods, without essaying even a cursory review of their importance or their bearing on current scientific investigation;—and yet, from the true astronomical point of view, all these questions are at least secondary to the fundamental problems of finding the true position of the solar system in the stellar universe and determining the relative positions and motions of those stars that, within the range of telescopic vision, compose that universe.

To this latter phase of our science I ask your attention for a few minutes. These problems still lie at the foundation of the "old" astronomy and cannot be relegated to the limbo of useless rubbish or to the museum of curious relics, not even to make room for the newborn astro-physics. On this foundation must rest every astronomical superstructure that hopes to stand the tests of time and of observation, and the precision of the future science depends rigorously upon the accuracy with which this groundwork is laid.

This work was begun in the sixteenth century but, in spite of all the improvements in apparatus and in methods of analysis and research, a really satisfactory result has not yet been reached.

There is no more fascinating phase of the evolution of human thought and skill in the adaptation of means to ends than is found in the development of the mathematical and instrumental means for the determination of the positions and motions of the

* Extract from an address delivered before the American Association for the advancement of science at its Rochester meeting August 1892.

bodies included in the solar system. Accuracy in astronomical methods and results did not exist, even approximately, until after the revival of practical astronomy in Europe about the beginning of the sixteenth century; and, before the end of that period, the crude instruments of the early astronomers reached their highest perfection in the hands of the skilful genius of Uraniborg.

The invention of the telescope, the application of the pendulum to clocks, the invention of the micrometer, the combination of the telescope with the divided arc of a circle, the invention of the transit circle by Roemer, with many improvements in minor apparatus, distinctly stamp the seventeenth century as a remarkable period of preparation for the achievements of the next century.

From the standpoint of the modern mechanician the instruments at the Greenwich Observatory, in Bradley's time, were very imperfect in design and construction; and yet on the observations obtained by his skill and perseverence, depends the whole structure of modern fundamental astronomy. The use of the quadrant reached its highest excellence under Bradley's management.

The next advance, the real work with divided circles, began at Greenwich in 1811, under the direction of Pond. Since that epoch, theory and observation have held a nearly even course in the friendly race toward that elusive goal, perfection; and the end is not yet. A careful, but independent, determination of the relative right ascensions of the principal stars, supplemented by a rigorous adjustment of such positions with regard to the equinoctial points; and a similar determination of the relative zenith or polar distance of the same bodies, finally referred and adjusted to the equator or the pole,—seem in this brief statement to be, at least, simple problems. If, however, we examine the conditions in detail, the simplicity may not appear so evident; and this characteristic may prove to be one reason why this important branch of astronomical research is now so generally neglected.

In the first place, it must be understood that such an investigation cannot be completed in a few months. At least *two* and preferably *three* years' work in observing are necessary to secure good results. Skilled observers, and not more than two with the same instrument, are absolutely necessary. Such work can not be confided to students or beginners in the art of observing, or to observers who have acquired the habit of anticipating the transit of a star. The telescope and the circles, the objective and the micrometer, the clock and the level must be of the best quality, for imperfections in any of these essentials render the best results impossible. A thoroughly good astronomical clock is the rarest instrument in the astronomer's collection. It is not sufficient that a clock should have a uniform daily rate, the rate should be uniform for any number of minor periods during the twenty-four hours. The absolute personal error in observing transits should be determined at least twice a week, and when it is not well established it should be found every day. The level error should be found every two hours and the greatest care should be exercised in handling this important instrument. The division marks should not be etched on the level tube unless the values of the divisions are frequently examined, for, sooner or later, such tubes become deformed on account of the broken surface and are then worthless.

In the determination of zenith distances the effect of refraction plays such an important part that no work can rightly claim to be fundamental until the local refraction has been carefully investigated and special corrections to the standard tables, if necessary, have been deduced for each observing station. The ordinary mode of observing temperatures is quite inadequate to the importance of the phenomena. These observations should be made as near as possible in the mass of air through which the objective of the telescope is moved and also in the opening in the roof and the sides of the observing room where the outside air comes in contact with that in the building. The thermometers should all be mounted so that they may be whirled in that portion of the air where the temperature is desired, and they should be tested at least once a year to determine the change in the position of the zero of the scale. But a complete list of the things to be done, and of the errors to be avoided, are too voluminous for this occasion and are not necessary to show the complex character of the problem;—the suggestions, already made, must suffice.

For many years an immense number of observations of the larger or the so-called standard stars have been made at the principal observatories, for different purposes and with varying degrees of accuracy, but it is not certain that the work of the last thirty years, with all the advantages of improved apparatus, has resulted in more exact determination of even the *relative* right ascensions of such stars. There can be no doubt that the chronographic registration of star transits has given more accurate results for the smaller stars, but I think it is equally true that, in the case of first and second magnitude stars, at least, no improvement has been made in accuracy.

(TO BE CONTINUED.)

ASTRO-PHYSICS.

GRATINGS IN THEORY AND PRACTICE.*

HENRY A. ROWLAND.†

PART I.

It is not my object to treat the theory of diffraction in general but only to apply the simplest ordinary theory to gratings made by ruling grooves with a diamond on glass or metal. This study I at first made with a view of guiding me in the construction of the dividing engine for the manufacture of gratings, and I have given the present theory for years in my lectures. As the subject is not generally understood in all its bearings I have written it for publication.

Let p be the virtual distance reduced to vacuo through which a ray moves. Then the effect at any point will be found by the summation of the quantity

$$A \cos b(p - Vt) + B \sin b(p - Vt)$$

in which $b = \frac{2\pi}{l}$, l being the wave-length, V is the velocity reduced to vacuo, and t is the time. Making $\theta = \tan^{-1}\frac{A}{B}$ we can write this

$$\sqrt{A^2 + B^2} \sin[\theta + b(p - Vt)].$$

The energy or intensity is proportional to $(A^2 + B^2)$

Taking the expression

$$(A + iB)e^{-ib(p - Vt)},$$

when $i = \sqrt{-1}$, its real part will be the previous expression for the displacement. Should we use the exponential expression instead of the circular function in our summation we see that we can always obtain the intensity of the light by multiplying the final result by itself with $-i$ in place of $+i$, because we have

$$(A + iB)e^{-ib(p - Vt)} \times (A - iB)e^{ib(p - Vt)} = A^2 + B^2$$

* Communicated by the author.

† I am much indebted to Dr. Ames for looking over the proofs of this paper and correcting some errors. In the paper I have, in order to make it complete, given some results obtained previously by others, especially by Lord Rayleigh. The treatment is, however, new, as well as many of the results. My object was originally to obtain some guide to the effect of errors in gratings so that in constructing my dividing engine I might prevent their appearance if possible.

In cases where a ray of light falls on a surface where it is broken up, it is not necessary to take account of the change of phase at the surface but only to sum up the displacement as given above.

In all our problems let the grating be rather small compared with the distance of the screen receiving the light so that the displacements need not be divided into their components before summation.

Let the point x', y', z' be the source of light, and at the point x, y, z let it be broken up and at the same time pass from a medium of index of refraction I′ to one of I. Consider the disturbance at a point x'', y'', z'' in the new medium. It will be

$$e^{-ib(I\rho + I'p - Vt)}$$

where

$$\rho^2 = x''^2 + y''^2 + z''^2 + x^2 + y^2 + z^2 - 2(xx'' + yy'' + zz'').$$
$$p^2 = x'^2 + y'^2 + z'^2 + x^2 + y^2 + z^2 - 2(xx' + yy' + zz').$$

Let the point x, y, z be near the origin of co-ordinates as compared with x', y', z' or x'', y'', z'' and let α, β, γ and α', β', γ' be the direction cosines of ρ and p. Then, writing

$$\begin{aligned} R &= I'\sqrt{x'^2 + y'^2 + z'^2} + I\sqrt{x''^2 + y''^2 + z''^2} \\ \lambda &= I\alpha + I'\alpha' \\ \mu &= I\beta + I'\beta' \\ \nu &= I\gamma + I'\gamma' \end{aligned}$$

we have, for the elementary displacement,

$$e^{-ib[R - Vt - \lambda x - \mu y - \nu z + \kappa r^2]}$$

$$\text{where } \kappa = \tfrac{1}{2}\left[\frac{I'}{\sqrt{x'^2 + y'^2 + z'^2}} + \frac{I}{\sqrt{x''^2 + y''^2 + z''^2}}\right]$$

and $r^2 = x^2 + y^2 + z^2$.

This equation applies to light in any direction. In the special case of parallel light, for which $\kappa = 0$, falling on a plane grating with lines in the direction of z, one condition will be that this expression must be the same for all values of z.

Hence $\nu = 0$.

If N is the order of the spectrum and a the grating space we shall see further on that we also have the condition

$$ba\mu = 2\pi N = \frac{2\pi a}{l}\mu$$

The direction of the diffracted light will then be defined by the equations

$$\alpha'^2 + \beta'^2 + \gamma'^2 = 0$$
$$\mathrm{I}\gamma + \mathrm{I}'\gamma' = 0$$
$$\mathrm{I}\beta + \mathrm{I}'\beta' = \frac{l}{a}\mathrm{N}$$

Whence

$$\mathrm{I}'\alpha' = \mathrm{I}\sqrt{\alpha^2 + 2\frac{l}{\mathrm{I}a}\mathrm{N}\beta - \frac{l^2\mathrm{N}^2}{\mathrm{I}^2a^2}}$$
$$\mathrm{I}'\beta' = \frac{l}{a}\mathrm{N} - \mathrm{I}\beta$$
$$\mathrm{I}'\gamma' = -\mathrm{I}\gamma$$

In the ordinary case where the incident and diffracted rays are perpendicular to the lines of the grating, we can simplify the equations somewhat.

Let φ be the angle of incidence and ψ of diffraction as measured from the positive direction of X.

$$\lambda = \mathrm{I}' \cos \varphi + \mathrm{I} \cos \psi$$
$$\frac{l}{a}\mathrm{N} = \mu = \mathrm{I}' \sin \varphi + \mathrm{I} \sin \psi$$

$b = \dfrac{2\pi}{l}$ where l is the wave-length in vacuo.

In case of the reflecting grating $\mathrm{I} = \mathrm{I}'$ and we can write

$$\lambda = \mathrm{I}\{ \cos \varphi + \cos \psi \}$$
$$\frac{l}{a}\mathrm{N} = \mu = \mathrm{I}\{ \sin \varphi + \sin \psi \}$$

This is only a very elementary expression as the real value would depend on the nature of the obstacle, the angles, etc., but it will be sufficient for our purpose.

The disturbance due to any grating or similar body will then be very nearly

$$\int\int e^{-ib[\mathrm{R} - \mathrm{V}t - \lambda x - \mu y - \nu z + \kappa(x^2 + y^2 + z^2)]}ds.$$

where ds is a differential of the surface. For parallel rays, $\kappa = 0$.

Plane Gratings.

In this case the integration can often be neglected in the direction of z and we can write for the disturbance in case of parallel rays,

$$e^{-ib(\mathrm{R} - \mathrm{V}t)}\int\int e^{-ib[-\lambda x - \mu y]}ds.$$

Case I.—Simple Periodic Ruling.

Let the surface be divided up into equal parts in each of which one or more lines or grooves are ruled parallel to the axis of z.

The integration over the surface will then resolve itself into an integration over one space and a summation with respect to the number of spaces. For in this case we can replace y by $na + y$ where a is the width of a space and the displacement becomes

$$e^{-ib(R - Vt)} \Sigma e^{+ib\mu an} \int\int e^{+ib(\lambda x + \mu y)} ds$$

$$\text{but} \quad \Sigma_0^{n-1} e^{+ib\mu an} = e^{+i\frac{n-1}{2} ba\mu} \frac{\sin n \frac{ba\mu}{2}}{\sin \frac{ba\mu}{2}}$$

Multiplying the disturbance by itself with $-i$ in place of $+i$ we have for the light intensity

$$\left\{ \frac{\sin n \frac{ba\mu}{2}}{\sin \frac{ba\mu}{2}} \right\}^2 \left[\int e^{-ib(\lambda x + \mu y)} ds \right] \left[\int e^{+ib(\lambda x + \mu y)} ds \right]$$

The first term indicates spectral lines in positions given by the equation

$$\sin \frac{ba\mu}{2} = 0$$

with intensities given by the last integral. The intensity of the spectral lines then depends on the form of the groove as given by the equation $x = f(y)$ and upon the angles of incidence and diffraction. The first factor has been often discussed and it is only necessary to call attention to a few of its properties.

When $ba\mu = 2\pi N$, N being any whole number, the expression becomes n^2. On either side of this value the intensity decreases until $nba\mu' = 2\pi N$, when it becomes 0.

The spectral line then has a width represented by $\mu' - \mu'' = 2\frac{\mu}{n}$ nearly; on either side of this line smaller maxima exist too faintly to be observed. When two spectral lines are nearer together than half their width, they blend and form one line. The defining power of the spectroscope can be expressed in terms of the quotient of the wave-length by the difference of wave-length of two lines that can just be seen as divided. The defining power is, then,

$$nN^* = na\frac{\mu}{l}$$

Now na is the width of the grating. Hence, using a grating at a given angle, the defining power is independent of the number of lines to the inch and only depends on the width of the grating and the wave-length. According to this, the only object of ruling many lines to the inch in a grating is to separate the spectra so that, with a given angle, the order of spectrum shall be less.

Practically the gratings with few lines to the inch are much better than those with many, and hence have *better* definition at a given angle than the latter except that the spectra are more mixed up and more difficult to see.

It is also to be observed that the defining power increases with shorter wave-lengths, so that it is three times as great in the ultra-violet as in the red of the spectrum. This is of course the same with all optical instruments such as telescopes and microscopes.

The second term which determines the strength of the spectral lines will, however, give us much that is new.

First let us study the effect of the shape of the groove on the brightness. If N is the order of the spectrum and a the grating space we have

$$\mu = \mathrm{I}(\sin\varphi + \sin\psi) = \frac{Nl}{a}$$

since $\sin\frac{ba\mu}{2} = 0$

and the intensity of the light becomes proportional to

$$\left[\int\int e^{i\,2\pi(\frac{\lambda}{l}x + \frac{N}{a}y)}\,ds\right]\left[\int\int e^{-i\,2\pi(\frac{\lambda}{l}x + \frac{N}{a}y)}\,ds\right]$$

It is to be noted that this expression is not only a function of N but also of l, the wave-length. This shows that the intensity in general may vary throughout the spectrum according to the wave-length and that the sum of the light in any one spectrum is not always white light.

This is a peculiarity often noticed in gratings. Thus one spectrum may be almost wanting in the green, while another may contain an excess of this color; again there may be very little blue in one spectrum while very often the similar spectrum on the other side may have its own share and that of the other one also. For this reason I have found it almost impossible to predict what the ultra red spectrum may be, for it is often weak even where the visible spectrum is strong.

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* An expression of Lord Rayleigh's.

The integral may have almost any form although it will naturally tend to be such as to make the lower orders the brightest when the diamond rules a single and simple groove. When it rules several lines or a compound groove, the higher orders may exceed the lower in brightness and it is mathematically possible to have the grooves of such a shape that, for given angles, all the light may be thrown into one spectrum.

It is not uncommon, indeed very easy, to rule gratings with immensely bright first spectra, and I have one grating where it seems as if half the light were in the first spectrum on one side. In this case there is no reflection of any account from the grating held perpendicularly: indeed to see one's face, the plate must be held at an angle, in which case the various features of the face are seen reflected almost as brightly as in a mirror but drawn out into spectra. In this case all the other spectra and the central image itself are very weak.

In general it would be easy to prove from the equation that want of symmetry in the grooves produces want of symmetry in the spectra, a fact universally observed in all gratings and one which I generally utilize so that the light may be concentrated in a few spectra only.

Example I. Square Grooves.

When the light falls nearly perpendicularly on the plate, we need not take the sides into account but only sum up the surface of the plate and the bottom of the groove. Let the depth be X and the width equal to $\frac{a}{m}$.

The intensity then becomes proportional to

$$\frac{1}{N^2}\sin^2\pi\frac{N}{m}\sin^2\pi\frac{\lambda}{l}X$$

This vanishes when

$$N = m,\ 2m,\ 3m,\ \text{etc.}$$

$$\text{or,}\quad \frac{\lambda X}{l} = 0,\ 1,\ 2,\ 3,\ \text{etc.}$$

The intensity of the central light, for which $N = 0$, will be

$$\frac{\pi^2}{m^2}\sin^2\left(\pi\frac{\lambda}{l}X\right).$$

This can be made to vanish for only one angle for a given wave-length. Therefore, the central image will be colored and the color will change with the angle, an effect often observed in actual gratings. The color ought to change, also, on placing the grating in a liquid of different index of refraction since λ contains I, the index of refraction.

It will be instructive to take a special case, such as light falling perpendicularly on the plate. For this case

$$\varphi = 0,\ \lambda = \mathrm{I}(1 + \cos \psi) \text{ and } \mu = \mathrm{I} \sin \psi = \frac{\mathrm{N}l}{a}.$$

Hence, $\lambda = \mathrm{I}\left\{1 + \sqrt{1 - \left(\frac{\mathrm{N}l}{a\mathrm{I}}\right)^2}\right\}$.

The last term in the intensity will then be

$$\sin^2 \left\{ \pi \mathrm{X} \mathrm{I}\left[\frac{1}{l} + \sqrt{\frac{1}{l^2} - \left(\frac{\mathrm{N}}{a\mathrm{I}}\right)^2}\right]\right\}.$$

As an example, let the green of the second order vanish. In this case, $l = .00005$. $\mathrm{N} = 2$. Let $a = .0002$ c.m. and $\mathrm{I} = 1$.

$$\text{Then,}\quad \mathrm{X}\left[20000. + \sqrt{(20000)^2 - (10000)^2}\right] = n.$$

$$\text{Whence,}\quad \mathrm{X} = \frac{n}{37300.}$$

where n is any whole number. Make it 1.

Then the intensity, as far as this term is concerned, will be as follows:

	Minima where Intensity is 0. Wave-lengths.		Maxima where Intensity is 1 Wave-lengths.		
1st spec.	.0000526	.0000268	.0001000	.00003544	.00002137
2nd "	.0000500	.0000266	.0000833	.00003463	.00002119
3rd "	.0000462	.0000263	.0000651	.00003343	.00002089
4th "	.0000416	.0000259	.0000499	.00003169	.00002050
5th "	etc.		etc.	etc.	

The central light will contain the following wave-lengths as a maximum:

.0001072 .00003575 .0000214, etc.

Of course it would be impossible to find a diamond to rule a rectangular groove as above and the calculations can only be looked upon as a specimen of innumerable light distributions according to the shape of groove.

Every change in position of the diamond gives a different light distribution and hundreds of changes may be made every day and yet the same distribution will never return, although one may try for years.

Example 2.—Triangular Groove.

Let the space a be cut into a triangular groove, the equations of the sides being $x = -cy$, and $x = c'(y - a)$, the two cuttings coming together at the point $y = u$. Hence we have $-cu = c'(u - a)$, and $ds = dy\sqrt{1 + c^2}$, or $dy\sqrt{1 + c'^2}$. Hence the intensity is proportional to

$$l^2 \left\{ \frac{1 + c^2}{(\mu - c\lambda)^2}\sin^2\frac{\pi u(\mu - c\lambda)}{l} + \frac{1 + c'^2}{(\mu + c'\lambda)^2}\sin^2\frac{\pi(a - u)(\mu + c'\lambda)}{l} \right.$$

$$+ \frac{\sqrt{(1 + c^2)(1 + c'^2)}}{(\mu - cy)(\mu + c'\lambda)}\sin\frac{\pi u(\mu - c\lambda)}{l}\sin\frac{\pi(a - u)(\mu + c'\lambda}{l}$$

$$\left. \cos\frac{\pi}{l}[(\mu + c'\lambda)(a - u) - n(\mu - c\lambda)] \right\}$$

This expression is not symmetrical with respect to the normal to the grating, unless the groove is symmetrical, in which case $c = c'$ and $u = \frac{a}{2}$.

In this case, as in the other, the colors of the spectrum are of variable intensity, and some of them may vanish as in the first example, but the distribution of intensity is in other respects quite different.

Case 2.—Multiple Periodic Ruling.

Instead of having only one groove ruled on the plate in this space a, let us now suppose that a series of similar lines are ruled.

We have, then, to obtain the displacement by the same expression as before, that is

$$\frac{\sin n\frac{ba\mu}{2}}{\sin\frac{ba\mu}{2}}\int e^{ib(\lambda n + \mu y)}ds,$$

except that the last integral will extend over the whole number of lines ruled within the space a.

In the spaces a let a number of equal grooves be ruled commencing at the points $y = 0$, y_1, y_2, y_3, etc., and extending to the points w, $y_1 + w$, $y_2 + w$, etc. The surface integral will then be divided into portions from w to y_1, from $y_1 + w$, to y_2, etc., on the original surface of the plate for which $x = 0$, and from w to 0, from $y_1 + w$ to y_1, etc., for the grooves.

The first series of integrals will be

$$\int e^{ib\mu y}dy = \left\{\frac{1}{ib\mu}\right\}\left\{-e^{ib\mu w}+e^{ib\mu y_1}-e^{ib\mu(y_1+w)}+e^{ib\mu y_2}-\text{etc.}\right\}$$

$$=\frac{1}{ib\mu}\left\{-e^{ib\mu w}+\left(1-e^{ib\mu w}\right)\left(e^{ib\mu y_1}+e^{ib\mu y_2}+\text{etc.}\right)+e^{ib\mu a}\right\}$$

But, $e^{ib\mu a}=1$ since $b\mu a=0$ for any maximum, and thus the integral becomes

$$\frac{1-e^{ib\mu w}}{ib\mu}\left\{1+e^{ib\mu y_1}+e^{ib\mu y_2}+\text{etc.}\right\}$$

The second series of integrals will be

$$\int_0^w e^{ib(\lambda n+\mu y)}ds.\left\{1+e^{ib\mu y_1}+\text{etc.}\right\}$$

The total integral will then be

$$\frac{\sin n\frac{ba\mu}{2}}{\sin\frac{ba\mu}{2}}\left[\frac{1-e^{ib\mu w}}{ib\mu}+\int_0^w e^{ib(\lambda x+\mu y)}ds\right]\left[1+e^{ib\mu y_1}+e^{ib\mu y_2}+\text{etc.}\right]$$

As before, multiply this by the same with the sign of i changed to get the intensity.

Example I.—Equal Distances.

The space, a, contains $n'-1$ equidistant grooves, so that $y_1=y_2-y_1=\text{etc.},=\frac{a}{n'}$

$$\Sigma_0^{n'-1}e^{ib\mu\frac{a}{n'}n}=e^{iba\mu}\frac{\sin\frac{ba\mu}{2}}{\sin\frac{ba\mu}{2n'}}$$

Hence the displacement becomes

$$\frac{\sin n\frac{ba\mu}{2}}{\sin\frac{ba\mu}{2n'}}\left[\frac{1-e^{ib\mu w}}{ib\mu}+\int_0^w e^{ib(\lambda x+\mu y)}ds.\right]$$

As the last term is simply the integral over the space $\frac{a}{n'}$ in a different form from before, this is a return to the form we previously had except that it is for a grating of nn' lines instead of n lines, the grating space being $\frac{a}{n'}$.

EXAMPLE II.—TWO GROOVES.

$$1 + e^{ib\mu y_1} = 2e^{\frac{ib\mu y_1}{2}} \cos \frac{b\mu y_1}{2}$$

But $ba\mu = 2N\pi$. Hence this becomes

$$2e^{i\pi N\frac{y_1}{a}} \cos \pi N\frac{y_1}{a}.$$

The square of the last term is a factor in the intensity. Hence the spectrum will vanish when we have

$$N\frac{y_1}{a} = \tfrac{1}{2}, \tfrac{3}{2}, \tfrac{5}{2}, \text{etc.*}$$

$$\text{or, } N = \frac{1}{2}\frac{a}{y_1}, \frac{3}{2}\frac{a}{y_1}, \frac{5}{2}\frac{a}{y_1}, \text{etc.}$$

Thus when $\frac{a}{y_1} = 2$, the 1st, 3d, etc., spectra will disappear making a grating of twice the number of lines to the c.m.

When $\frac{a}{y_1} = 4$, the 2d, 6th, 10th, etc, spectra disappear. When $\frac{a}{y_1} = 6$, the 3d, 9th, etc., spectra disappear.

The case in which $\frac{a}{y_1} = 4$, as Lord Rayleigh has shown, would be very useful as the second spectrum disappears leaving the red of the first and the ultra violet of the third without contamination by the second. In this case two lines are ruled and two left out. This would be easy to do but the advantages would hardly pay for the trouble owing to the following reasons: Suppose the machine was ruling 20,000 lines to the inch. Leaving out two lines and ruling two would reduce the dispersion down to a grating with 5,000 lines to the inch. Again, the above theory assumes that the grooves do not overlap. Now I believe that in nearly, if not all, gratings with 20,000 lines to the inch the whole surface is cut away and the grooves overlap. This would cause the second spectrum to appear again after all our trouble.

Let the grooves be nearly equidistant, one being slightly displaced. In this case $y_1 = \frac{a}{2} + v$.

$$\cos^2 \pi \frac{Ny_1}{a} = \left(\cos \frac{\pi N}{2} \cos \frac{\pi N v}{a} - \sin \frac{\pi N}{2} \sin \frac{\pi N v}{a}\right)^2$$

For the even spectra this is very nearly unity, but for the odd it becomes

* A thorem of Lord Rayleigh's.

$$\left(\pi N \frac{v}{a}\right)^2$$

Hence the grating has its principal spectra like a grating of space $\frac{a}{2}$, but there are still the intermediate spectra due to the space a, and of intensities depending on the *squares* of the order of spectrum, and the squares of the relative displacement, a law which I shall show applies to the effect of all errors of the ruling.

This particular effect was brought to my attention by trying to use a tangent screw on the head of my dividing engine to rule a grating with say 28,872 lines to the inch, when a single tooth gave only 14,436 to the inch. However carefully I ground the tangent screw I never was able to entirely eliminate the intermediate spectra due to 14,436 lines, and make a pure spectrum due to 28,872 lines to the inch, although I could nearly succeed.

EXAMPLE 3.—ONE GROOVE IN m MISPLACED.

Let the space a contain m grooves equidistant except one which is displaced a distance v. The displacement is now proportional to

$$1 + e^{ib\mu\frac{a}{m}} + e^{2ib\mu\frac{a}{m}} + \text{etc.} + e^{ib\mu\left(p\frac{a}{m} + v\right)} + \text{etc.} + e^{ib\mu\frac{m-1}{m}a}$$

$$= e^{ib\mu\frac{m-1}{2m}a}\left\{\frac{\sin\frac{b\mu a}{2}}{\sin\frac{b\mu a}{2m}} + ib\mu v\, e^{ib\mu a\frac{2p-m+1}{2m}}\right\}$$

Multiplying this by itself with $-i$ in place of $+i$, and adding the factors in the intensity, we have the whole expression for the intensity. One of the terms entering the expression will be

$$\frac{\sin n\frac{b\mu a}{2}}{\sin\frac{ba\mu}{2m}}\;\frac{\sin n\frac{ba\mu}{2}}{\sin\frac{ba\mu}{2}}\;\sin\frac{ba\mu}{2}\,\frac{2p-m+1}{m}$$

Now the first two terms have finite values only around the points $\frac{ba\mu}{2} = mN\pi$, where mN is a whole number. But $2p - m + 1$ is also a whole number, and hence the last term is zero at these points. Hence the term vanishes and leaves the intensity, omitting the groove factor,

$$\frac{\sin^2 n\frac{ba\mu}{2}}{\sin\frac{ba\mu}{2m}} + (b\mu v)^2\frac{\sin^2 n\frac{ba\mu}{2}}{\sin^2\frac{ba\mu}{2}}$$

The first term gives the principle spectra as due to a grating space of $\frac{a}{m}$ and number of lines nm as if the grating were perfect. The last term gives entirely new spectra due to the grating space, a, and with lines of breadth due to a grating of n lines and intensities equal to $(b\mu v)^2$.

Hence, when the tangent screw is used on my machine for 14,436 lines to the inch, there will still be present weak spectra due to the 14,436 spacing although I should rule say 400 lines to the *mm*. This I have practically observed also.

The same law holds as before that the relative intensity in these subsidiary spectra varies as the square of the order of the spectrum and the square of the deviation of the line, or lines from their true position.

So sensitive is a dividing engine to periodic disturbances that all the belts driving the machine must never revolve in periods containing an aliquot number of lines of the grating; otherwise they are sure to make spectra due to their period.

As a particular case of this section we have also to consider

Periodic Errors of Ruling.—Theory of "Ghosts."

In all dividing engines the errors are apt to be periodic due to "drunken" screws, eccentric heads, imperfect bearings, or other causes. We can then write

$$y = n_0 a + a_1 \sin(e_1 n) + a_2 \sin(e_2 n), + \text{etc.}$$

The quantities e_1, e_2, etc., give the periods, and a_1, a_2, etc., the amplitudes of the errors. We can then divide the integral into two parts as before, an integral over the groove and spaces and a summation with respect to the numbers.

$$\Sigma\int_{y'}^{y''} e^{-ib(\lambda x+\mu y)}ds = \Sigma e^{-ib\mu y}\int_0^{y''-y'} e^{-ib(\lambda n+\mu y)}ds$$

It is possible to perform these operations exactly, but it is less complicated to make an approximation, and take $y''-y' = a$, a constant as it is very nearly in all gratings. Indeed the error introduced is vanishingly small. The integral which depends on the shape of the groove, will then go outside the summation sign and we have to perform the summation

$$\Sigma\, e^{-ib\mu\{a_0 n + a_1 \sin e_1 n + a_2 \sin e_2 n + \text{etc.}\}}$$

Let J_n be a Bessel's function. Then

$$\cos(u \sin \varphi) = J_0(u) + 2[J_2(u)\cos_2\varphi + J_4(u)\cos_4\varphi + \text{etc.}$$

$$\sin(u \sin \varphi = \qquad 2(J_1(u)\sin\varphi + J_3(u)\sin_3\varphi + \text{etc.}$$

But $e^{-iu\sin\varphi} = \cos(u\sin\varphi) - i\sin(u\sin\varphi.)$

Hence the summation becomes

$$\Sigma \begin{cases} e^{-ib\mu a_0 n} \\ \times\, [J_0(b\mu a_1) + 2(-iJ_1(b\mu a_1)\sin e_1 n + J_2(b\mu a_1)\cos 2e_1 n - \text{etc.})] \\ \times\, [J_0(b\mu a_2) + 2(-iJ_1(b\mu a_2)\sin e_2 n + J_2(b\mu a_2)\cos 2e_1 n - \text{etc.})] \\ \times\, [J_0(b\mu a_3) + \text{etc.} \qquad\qquad)] \\ \times\, [\text{etc.} \end{cases}$$

CASE I.—SINGLE PERIODIC ERROR.

In this case only a_0 and a_1 exist. We have the formula

$$\Sigma_0^{n-1} e^{-ipn} = e^{-i\frac{n-1}{2}p} \frac{\sin\frac{pn}{2}}{\sin\frac{p}{2}}$$

Hence the expression for the intensity becomes

$$\left\{ J_0(b\mu a_1) \frac{\sin n\frac{b\mu a_0}{2}}{\sin\frac{b\mu a_0}{2}} \right\}^2 + J_1^2(b\mu a_1) \left\{ \left(\frac{\sin n\frac{b\mu a_0 + e_1}{2}}{\sin\frac{b\mu a_0 + e_1}{2}} \right)^2 + \left(\frac{\sin n\frac{b\mu a_0 - e_1}{2}}{\sin\frac{b\mu a_0 - e_1}{2}} \right)^2 \right\} + \text{etc.}$$

As n is large, this represents various very narrow spectral lines whose light does not overlap and thus the different terms are independent of each other. Indeed in obtaining this expression the products of quantities have been neglected for this reason because one or the other is zero at all points. These lines are all alike in relative distribution of light and their intensities and positions are given by the following table.

Places.	*Intensities.*	*Designations.*
$\mu = \dfrac{2\pi N}{ba_0}$	$J_0^2(b\mu a_1)$	Primary lines.
$\mu_1 = \mu \pm \dfrac{e_1}{ba_0}$	$J_1^2(b\mu_1 a_1)$	Ghosts of 1st order.
$\mu_2 = \mu \pm \dfrac{2e_1}{ba_0}$	$J_2^2(b\mu_1 a_2)$	Ghosts of 2d order.
$\mu_3 = \mu \pm \dfrac{3e_1}{ba_0}$	$J_3^2(b\mu_3 a_1)$	Ghosts of 3d order.
etc.	etc.	etc.

Hence the light which would have gone into the primary line now goes to making the ghosts, so that the total light in the line and its ghosts is the same as in the original without ghosts.

The relative intensities of the ghosts as compared with the primary line is

$$\frac{J_n^2(b\mu a_1)}{J_0^2\,(b\mu a_1)}$$

This for very weak ghosts of the first, second, third, etc., order, becomes

$$\left(\pi N \frac{a_1}{a_0}\right)^2, \quad \frac{1}{2}\left(\pi N \frac{a_1}{a_0}\right)^4, \quad \frac{1}{6}\left(\pi N \frac{a_1}{a_0}\right)^6, \text{ etc.}$$

The intensity of the ghosts of the first order varies as the square of the order of the spectrum and as the square of the relative displacement as compared with the grating space a_0. This is the same law as we before found for other errors of ruling, and it is easy to prove that it is general. Hence

The effect of small errors of ruling is to produce diffused light around the spectral lines. This diffused light is subtracted from the light of the primary line, and its comparative amount varies as the square of the relative error of ruling and the square of the order of the spectrum.

Thus the effect of the periodic error is to diminish the intensity of the ordinary spectral lines (primary lines) from the intensity 1 to $J_0^2(b\mu a_1)$, and surround it with a symmetrical system of lines called ghosts, whose intensities are given above.

When the ghosts are very near the primary line, as they nearly always are in ordinary gratings ruled on a dividing engine with a large number of teeth in the head of the screw, we shall have

$$J_1^2 ba_1\left(\mu + \frac{e_1}{ba_0}\right) + J_1^2 ba_1\left(\mu - \frac{e_1}{ba_0}\right) = 2J_1^2 ba_1\mu \text{ nearly.}$$

Hence the total light is by a known theorem,

$$J_0^2 + 2[J_1^2 + J_2^2 + \text{etc.} = 1.$$

Thus, in all gratings, the intensity of the ghosts as well as the diffused light increases rapidly with the order of the spectrum. This is often marked in gratings showing too much crystalline structure. For the ruling brings out the structure and causes local difference of ruling which is equivalent to error of ruling as far as diffused light is concerned.

For these reasons it is best to get defining power by using broad gratings and a low order of spectra although the increased perfection of the smaller gratings makes up for this effect in some respects.

There is seldom advantage in making both the angle of incidence and diffraction more than 45°, but, if the angle of incidence is 0, the other angle may be 60°, or even 70°, as in concave gratings. Both theory and practice agree in these statements.

Ghosts are particularly objectionable in photographic plates, especially when they are exposed very long. In this case ghosts may be brought out which would be scarcely visible to the eye.

As a special case, take the following numerical results:

$$\begin{array}{cccccccccccc}
N & = & & 1 & & & 2 & & & 3 & \\
\dfrac{a_1}{a_0} & = & \dfrac{1}{25}, & \dfrac{1}{50}, & \dfrac{1}{100} & \dfrac{1}{25}, & \dfrac{1}{50}, & \dfrac{1}{100} & \dfrac{1}{25}, & \dfrac{1}{50}, & \dfrac{1}{100} \\
\left(\pi N \dfrac{a_1}{a_0}\right)^2 & = & \dfrac{1}{63}, & \dfrac{1}{252}, & \dfrac{1}{1008} & \dfrac{1}{16}, & \dfrac{1}{63}, & \dfrac{1}{252} & \dfrac{1}{7}, & \dfrac{1}{28}, & \dfrac{1}{102}
\end{array}$$

In a grating with 20,000 lines to the inch, using the third spectrum, we may suppose that the ghosts corresponding to $\frac{a_1}{a_0} = \frac{1}{50}$ will be visible and those for $\frac{a_1}{a_0} = \frac{1}{25}$ very troublesome. The first error is $a_1 = \frac{1}{1000000}$ in. and the second $a_1 = \frac{1}{500000}$ in. Hence a periodic displacement of one millionth of an inch will produce visible ghosts and one five hundred thousandth of an inch will produce ghosts which are seen in the second spectrum and are troublesome in the third. With very bright spectra these might even be seen in the first spectrum. Indeed an over exposed photographic plate would readily bring them out.

When the error is very great, the primary line may be very faint or disappear altogether, the ghosts to the number of twenty or fifty or more being often more prominent than the original line. Thus, when

$$b\mu a_1 = 2.405,\ 5.52,\ 8.65 \text{ etc.} \quad = 2\pi N \frac{a_1}{a_0}$$

the primary line disappears. When

$$b\mu a_1 = 0,\ 3.83,\ 7.02 \text{ etc.} \quad = 2\pi N \frac{a_1}{a_0},$$

the ghosts of the first order will disappear. Indeed we can make any ghost disappear by the proper amount of error.

Of course, in general

$$J_n = \frac{2(n-1)}{v} J_{n-1} - J_{n-2}.$$

Thus a table of ghosts can be formed readily and we may always tell when the calculation is complete by taking the sum of the light and finding unity.

$2\pi N \frac{a_1}{a_0}$	J_0^2	J_1^2	J_2^2	J_3^2	J_4^2	J_5^2	J_6^2	J_7^2	J_8^2	J_9^2	J_{10}^2	J_{11}^2	J_{12}^2	J_{13}^2	J_{14}^2
0.	1.000	—	—	—	—	—	—	—	—	—	—	—	—	—	—
.2	.980	.010	—	—	—	—	—	—	—	—	—	—	—	—	—
.4	.922	.038	—	—	—	—	—	—	—	—	—	—	—	—	—
.6	.832	.082	.002	—	—	—	—	—	—	—	—	—	—	—	—
.8	.716	.136	.005	—	—	—	—	—	—	—	—	—	—	—	—
1.0	.586	.194	.012	—	—	—	—	—	—	—	—	—	—	—	—
2.0	.050	.333	.124	.017	.001	—	—	—	—	—	—	—	—	—	—
2.605	.000	.269	.186	.040	.003	—	—	—	—	—	—	—	—	—	—
3	.068	.115	.236	.095	.017	.002	—	—	—	—	—	—	—	—	—
3.832	.162	.000	.162	.176	.065	.013	.002	—	—	—	—	—	—	—	—
4.0	.158	.004	.133	.185	.079	.018	.002	—	—	—	—	—	—	—	—
5.0	.031	.107	.002	.133	.153	.068	.017	.003	—	—	—	—	—	—	—
5.520	.000	.116	etc.												
6.0	.022	.077	.059	.013	.128	.131	.061	.017	.003	—	—	—	—	—	—
7.016	.090	.000	.090	etc.											
8	.029	.055	.013	.085	.011	.035	.114	.103	.050	.016	.003	.001	—	—	—
8.654	.000	.075	etc.												
10.	.060	.002	.065	.003	.048	.055	.002	.047	.101	.091	.051	.022	.011	.009	.022

This table shows how the primary line weakens and the ghosts strengthen as the periodic error increases, becoming 0 at $2\pi N \frac{a'}{a} = 2.405$. It then strengthens and weakens periodically, the greatest strength being transferred to one of the ghosts of higher and higher order as the error increases.

Thus one may obtain an estimate of the error from the appearance of the ghost.

Some of these wonderful effects with 20 to 50 ghosts stronger than the primary line I have actually observed in a grating ruled on one of my machines before the bearing end of the screw had been smoothed. The effect was very similar to these calculated results.

Double Periodic Error.

Supposing as before that there is no overlapping of the lines, we have the following:

Places.	*Intensities.*	
$\mu = \dfrac{2\pi N}{ba_0}$	$\left[J_0(b_1a_1\mu)\ J_0(ba_2\mu)\right]^2$	Primary line.
$\mu_1 = \mu \pm \dfrac{e_1}{ba_0}$	$\left[J_1(ba_1\mu_1)\ J_0(ba_2\mu_1)\right]^2$	Ghosts of 1st order.
$\mu_2 = \mu \pm \dfrac{e_2}{ba_0}$	$\left[J_0(ba_1\mu_2)\ J_1(ba_2\mu_2)\right]^2$	
$\mu_3 = \mu \pm \dfrac{e_1 \pm e_2}{ba_0}$	$\left[J_1(ba_1\mu_3)\ J_1(ba_2\mu_3)\right]^2$	Ghosts of 2d order.
$\mu_4 = \mu \pm \dfrac{2e_1}{ba_0}$	$\left[J_2(ba_1\mu_4)\ J_0(ba_2\mu_4)\right]^2$	
$\mu_5 = \mu \pm \dfrac{2e_2}{ba_0}$	$\left[J_0(ba_1\mu_5)\ J_2(ba_2\mu_5)\right]^2$	
$\mu_6 = \mu \pm \dfrac{e_1 \pm 2e_2}{ba_0}$	$\left[J_1(ba_1\mu_6)\ J_2(ba_2\mu_6)\right]^2$	Ghosts of 3d order.
$\mu_7 = \mu \pm \dfrac{2e_1 \pm e_2}{ba_0}$	$\left[J_2(ba_1\mu_7)\ J_1(ba_2\mu_7)\right]^2$	
$\mu_8 = \mu \pm \dfrac{3e_1}{ba_0}$	$\left[J_0(ba_1\mu_8)\ J_3(ba_2\mu_8)\right]^2$	
$\mu_9 = \mu \pm \dfrac{3e_2}{ba_0}$	$\left[J_3(ba_2\mu_9)\ J_0(ba_2\mu_9)\right]^2$	
etc.	etc.	

Each term in this table of ghosts simply expresses the fact that each periodic error produces the same ghosts in the same place as if it were the only error, while others are added which are the ghosts of ghosts. The intensities, however, are modified in the presence of these others.

Writing $c_1 = ba_1\mu$ and $c_2 = ba\mu_2$.

The total light is

$$J_0^2(c_1)\,J_0^2(c_2) + \begin{Bmatrix} 2J_1^2(c_1)\,J_0^2(c_2) \\ +\,2J_0^2(c_1)\,J_1^2(c_2) \end{Bmatrix} + \begin{Bmatrix} 2J_2^2(c_1)\,J_0^2(c_2) \\ +\,4J_1^2(c_1)\,J_1^2(c_2) \\ +\,2J_0^2(c_1)\,J_2^2(c_2) \end{Bmatrix} + \text{etc.}$$

which we can prove to be equal to 1.

Hence the sum of all the light is still unity, a general proposition which applies to any number of errors.

The positions of the lines when there is any number of periodic errors can always be found by calculating first the ghosts due to each error separately; then the ghosts due to these primary ghosts for it as if it were the primary line, and so on *ad infinitum*.

In case the ghosts fall on top of each other the expression for the intensity fails. Thus when $e_2 = 2e_1$, $e_3 = 3e_1$, etc., the formula will need modification. The positions are in this case only those due to a single periodic error, but the intensities are very different.

Places.

$$\begin{array}{ll}
\mu = \dfrac{2\pi N}{ba_0} & [J_0(ba_1\mu)J_0(ba_2\mu)]^2 \\
\mu_1 = \mu \pm \dfrac{e_1}{ba_0} & [J_1(ba_1\mu_1)\,J_0(ba_2\mu_1) - J_3(ba_1\mu_1)J_2(ba_2\mu_1) + \text{etc.}]^2 \\
 & + [J_1(ba_1\mu_1)\,J_1(ba_2\mu_1) - J_3(ba_1\mu_1)J({}_1ba_2\mu_1) + \text{etc.}]^2 \\
\text{etc.} & \text{etc.}
\end{array}$$

We have hitherto considered cases in which the error could not be corrected by any change of focus in the objective. It is to be noted, however, that for any given angle and focus, every error of ruling can be neutralized by a proper error of the surface, and that all the results we have hitherto obtained for errors of ruling can be produced by errors of surface, and many of them by errors in size of groove cut by the diamond. Thus ghosts are produced not only by periodic errors of ruling but by periodic waves in the surface, or even by a periodic variation in the depth of ruling. In general, however, a given solution will apply only to one angle and, consequently, the several results will not be identical; in some cases, however, they are perfectly so.

Let us now take up some cases in which change of focus can occur. The term $\varkappa r^2$ in the original formula must now be retained.

Let the lines of the grating be parallel to each other. We can then neglect the terms in z and can write $r^2 = y^2$ very nearly. Hence the general expression becomes

$$\int e^{ib(\lambda x + \mu y - \varkappa y^2)} ds,$$

where $\varkappa$ depends on the focal length. This is supposed to be very large, and hence $\varkappa$ is small.

This integral can be divided into two parts, an integral over the groove and the intervening space, and a summation for all the grooves. The first integral will slightly vary with change in the distance of the grooves apart, but this effect is vanishingly small compared with the effect on the summation, and can thus be neglected. The displacement is thus proportional to

$$\Sigma e^{ib(\mu y - \varkappa y^2)}$$

Case 1.—Lines at Variable Distances.

In this case we can write in general

$$y = an + a_1 n^2 + a_2 n^3 + etc.$$

As $\varkappa$, a_1, a_2, etc., are small, we have for the displacement, neglecting the products of small quantities,

$$\Sigma e^{ib[\mu(an + a_1 n^2 + a_2 n^3 + \text{etc.}) - \varkappa a^2 n^2]}$$

Hence the term $a_1 n^2$ can be neutralized by a change of forms expressed by $\mu a_1 = \varkappa a^2$. Thus a grating having such an error will have a different focus according to the angle n, and the change will be + on one side and — on the other.

This error often appears in gratings and, in fact, few are without it.

A similar error is produced by the plate being concave, but it can be distinguished from the above error by its having the focus at the same angle on the two sides the same instead of different.

According to this error, $a_1 n^2$, the spaces between the lines from one side to the other of the grating, increase uniformly in the same manner as the lines in the B group of the solar spectrum are distributed. Fortunately it is the easiest error to make in ruling, and produces the least damage.

The expression to be summed can be put in the form

$$\Sigma e^{ib\mu an}[1 + ib(\mu a_1 - \varkappa a^2)n^2 + ib\mu a_2 n^3 + ib[\mu a_3 + ib(\mu a_1 - \varkappa a^2)^2]n^4 + \text{etc.}]$$

The summation of the different terms can be obtained as shown below, but, in general, the best result is usually sought by changing the focus. This amounts to the same as varying $\varkappa$ until $\mu a_1 - \varkappa a^2 = 0$ as before. For the summation we can obtain the following formula from the one already given. Thus

$$\Sigma_0^{n-1} e^{2ipn} = \frac{\sin np}{\sin p} e^{ip(n-1)}$$

Hence

$$\Sigma_0^{n-1} n^m e^{2ipn} = \frac{1}{(2i)^m} e^{ip(n-1)} \left(\frac{d}{dp} + i(n-1)\right)^m \frac{\sin np}{\sin p}$$

When n is very large, writing $\frac{b\mu an}{2} = pn = \pi Nn + q$, we have

$$\Sigma_0^{n-1} n^m e^{2ipn} = \frac{n^{m+1}}{(2i)^m} e^{iq} \left(\frac{d}{dq} + i\right)^m \frac{\sin q}{q}$$

Whence writing

$$\begin{aligned} c &= b(\mu a_1 - \varkappa a^2) \\ c' &= b\mu a_2 \\ c'' &= b[\mu a_3 + ib(\mu a_1 - \varkappa a^2)^2] \\ c''' &= \text{etc.} \end{aligned}$$

the summation is

$$e^{iq}\left\{\begin{array}{l} n + i\left(c\dfrac{n^3}{4} + c'\dfrac{n^4}{8} + c''\dfrac{n^5}{16} + \right) \\ + \left(2c\dfrac{n^3}{4} + 3c'\dfrac{n^4}{8} + 4c''\dfrac{n^5}{16} + \right)\dfrac{d}{dq} \\ - i\left(c\dfrac{n^3}{4} + 3c'\dfrac{n^4}{8} + 6c''\dfrac{n^5}{16} + \right)\dfrac{d^2}{dq^2} \\ \qquad\qquad - \left(c'\dfrac{n^4}{8} + 4c''\dfrac{n^5}{16} + \right)\dfrac{d^3}{dq^3} \\ \qquad\qquad\qquad + i\left(c''\dfrac{n^5}{16} + \right)\dfrac{d^4}{dq^4} \\ \qquad\qquad\qquad\qquad + \text{etc.} \end{array}\right\}\frac{\sin q}{q}$$

$$\begin{aligned} \frac{d}{dq}\frac{\sin q}{q} &= \frac{q\cos q - \sin q}{q^2} \\ \frac{d^2}{dq^2}\frac{\sin q}{q} &= \frac{-2q\cos q + (2-q^2)\sin q}{q^3} \\ \frac{d^3}{dq^3}\frac{\sin q}{q} &= \frac{q(6-q^2)\cos q - (6-3q^2)\sin q}{q^4} \\ \text{etc.} & \qquad\qquad \text{etc.} \end{aligned}$$

These equations serve to calculate the distribution of light intensity in a grating with any error of line distribution suitable to this method of expansion and at any focal length. For this purpose the above summation must be multiplied by itself with $+ i$ in place of $- i$.

The result is for the light intensity

$$\begin{aligned} &\left\{ n\frac{\sin q}{q} + \left(2c\frac{n^3}{4} + 2c\frac{n^4}{8} + \text{etc.}\right)\frac{d}{dq}\frac{\sin q}{q} \right. \\ &\qquad\qquad \left. - \left(c'\frac{n^4}{8} + 4c''\frac{n^5}{16} + \text{etc.}\right)\frac{d^3}{dq^3}\frac{\sin q}{q} + \textit{etc.} \right\}^2 \\ &+ \left\{ \left(c\frac{n^3}{4} + 3c'\frac{n^4}{8} + \text{etc.}\right)\frac{d^2}{dq^2}\frac{\sin q}{q} \right. \\ &\qquad\qquad \left. - \left(c''\frac{n^5}{16} + \text{etc.}\right)\frac{d^4}{dq^4}\frac{\sin q}{q} + \textit{etc.} \right\}^2 \end{aligned}$$

As might have been anticipated, the effect of the additional terms is to broaden out the line and convert it into a rather complicated group of lines; as can sometimes be observed with a bad grating. At any given angle the same effect can be produced by variation of the plate from a perfect plane. Likewise the effect of errors in the ruling may be neutralized for a given angle by errors of the ruled surface, as noted in the earlier portions of the paper.

OBSERVATIONS OF NOVA AURIGÆ FROM NOV. 9, TO DEC. 14, 1892.*

W. W. CAMPBELL.

The following observations of the chief nebular line in Nova Aurigæ's spectrum are additional to those already published:

1892.	Grating.	λ	Velocity.
Nov. 9	1st order.	5004.32	— 98 miles.
" 9	2d order.	5004.54	
" 16	1st order.	5004.86	— 80 miles.
" 16	2d order.	5004.94	
" 17	1st order.	5005.07	— 80 miles.
" 17	2d order.	5004.72	
" 17*	1st order.	5004.89	— 80 miles.
" 24	2d order.	5004.49	— 95 miles.
Dec. 13*	1st order.	5004.18	— 107 miles.
" 14*	1st order.	5004.02	— 109 miles.
" 14*	2d order.	5004.22	

The observations marked with an asterisk (*) were made by S. D. Townley, those in December having been secured in my absence from the Observatory. It will be noticed that his measure of Nov. 17 agrees exactly with the mean of the two made by me.

On November 7 I observed the line with our fourth order grating of 14,438 lines to the inch. The line was seen to be eight or nine tenth-meters broad, sloping equally and gradually in both directions. There was not the slightest trace of doubling. Though the dispersion in the fourth order is very nearly three times as great as in the second order, the measures of wavelength can be made more accurately with the latter on account of the greater brightness of the line.

Grand Rapids, Michigan, Dec. 22, 1892.

THE POTSDAM SPECTROGRAPH.*

EDWIN B. FROST.

The instrument was constructed for the express purpose of determining photographically the velocity of stellar motions in the line of sight. Incidentally it fulfils all the functions of a compound star spectroscope adapted for photography.

Preliminary experiments made by Professor Vogel and Dr. Scheiner in 1887 with a merely provisional apparatus demonstrated the entire feasibility of the method, and the spectrograph in its perfected form was applied to the work for which it was devised in September, 1888.

The results of this investigation, which was necessarily brought to a close in May, 1891, by the limitation of the light power of the refractor, are given in detail in Band VII, Theil I, of the *Publicationen des astrophysikalischen Observatoriums zu Potsdam* (Engelmann, Leipzig, 1892).†

We are here chiefly concerned with an explanation of the instrument itself, and shall, for the most part, follow the description given by Professor Vogel in that volume, from which the cuts are taken.

In designing the spectrograph the following essential conditions were laid down: (1) great stability, to secure against flexure of the individual parts, which would be fatal to measurements of displacements; (2) the least possible weight, to prevent flexure of the equatorial; (3) the best adaptation of the dimensions of the optical parts, in order to retain a maximum of light power with the highest available dispersion; (4) an accurate adjustment of the photographic plate in the focal plane of the camera lens, and (5) a reliable means of retaining the image of the star upon the slit.

The first of these conditions was met by the use of steel in most of the parts, yet the weight of the complete instrument is but 12 kg (= 26 lbs.).

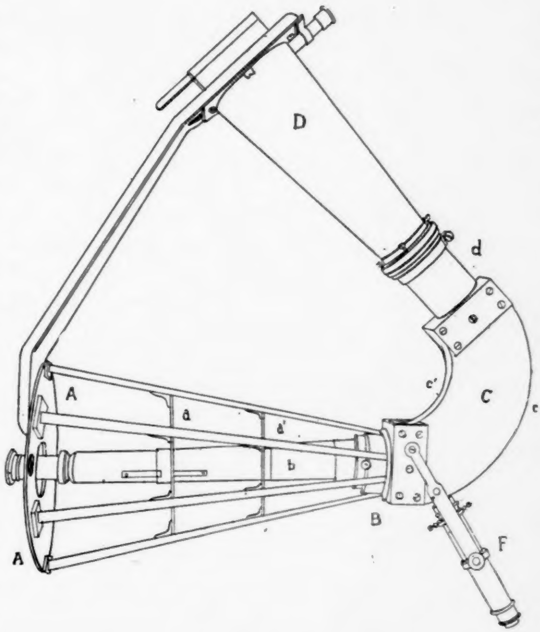
The nose-piece of the 12-inch refractor having been removed there is substituted for it a stout connecting frame of three iron rods, the ends of which are provided with screw threads; to these the flat steel base-plate, AA, of the spectrograph (see the small figure) is attached, being retained in position by nust on each

* Communicated by the author.

† Shorter articles will be found in *Monthly Notices*, December, 1891, and June, 1892, the first of which was reprinted in this journal in March, 1892.

side, so that it may be adjusted to be perpendicular to the optical axis of the refractor.

The holes in the base-plate are oval, so as to allow a slight rotation of the whole apparatus and thus permit the slit to be set precisely parallel to the equator. Six steel braces, T shaped in section, are riveted to the base-plate and unite in a stiff ring BB of cast brass.



Plates of sheet steel *a* and a^1 add stability, and support cylindrical collars through which the brass collimator-tube may be moved in the direction of its axis by a ratchet and pinion. The amount of this motion may be accurately read to 0.1 mm on a graduated scale. A tube *b*, which may be slid back far enough to give access to the collimating lens, shields it from extraneous light. C is a steel box, impervious to light, containing the prisms. It is rigidly connected with the ring B. The prisms are held between brass plates which are screwed to the box after they have been adjusted to the minimum of deviation for Hγ. Rigidly attached to the other end of the box is a brass tube *d*, in which the camera lens may be moved by a fine screw with divided head through a range of about 10 mm. The camera, D, of thin sheet steel, is attached to a flange at the end of the tube *d*, by screws which permit the camera to be adjusted to the axis of its objective. The outer end of the camera is rigidly joined to the base plate AA by two steel trusses. Thus the whole instrument is as a single piece, and when the "permanent" adjustments have been made (experience showed that they needed to be controlled only at long intervals of time), the only movable parts are the camera lens, the collimator as a whole, and the slit, the amount of all these motions being accurately measurable.

The blackened brass plate holders, of which six are provided, fit snugly in a frame at the end of the camera, and are of fine workmanship. The camera is adjusted so that the Hγ line falls at the middle of photographic plate, which is 80×15 mm in size.

An eye-piece may be attached behind the plate-holder for testing the adjustment of the spectrum on the plate, and a small reflecting prism makes it also possible to view a portion of the green rays through another eye-piece during the exposure.

F is a small telescope, focused for parallel rays, through which the slit (illuminated by the hydrogen light from the Geissler tube) and the star lying in it may be observed, the rays which are reflected from the first surface of the first prism being thus utilized. The small aperture in the prism-box necessary for the purpose is closed by a sliding cover when not in use, so as to exclude dust from the prisms. The slitis of simpledesign; but one of its jaw is movable, by a micrometer screw.

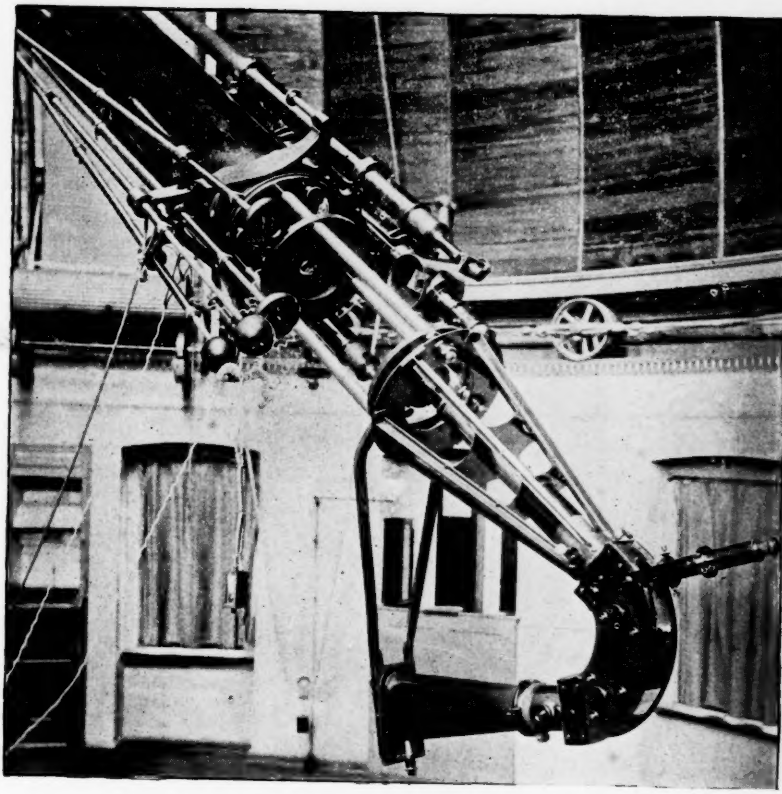
A metal diaphragm may be rotated before the slit. In it are cut several apertures—rectangles of from 2 to 10 mm length, other rectangles with a strip left across the middle, and one small circle. Thus the length of the slit may be varied,—which is very convenient, as it would be often tedious to bring the star to fall upon a slit only 2 mm long. When the desired aperture has been brought before the slit, it is held in its proper place by a spring catch. The objectives of the collimator and camera are corrected for the photographic rays and are made as thin as possible to diminish the absorption; their focal length is 408 mm and their aperture is 34 mm.

The preliminary experiments showed that two Rutherfurd compound prisms were best adapted to the purpose of this spectrograph, the use of a grating being impossible from the loss of light involved. They are of Jena glass, the angles of the flint prism being 94° 32′, of the crown prisms 18° 30′; the deviation of Hγ for a single prism is 66° 28′, and the dispersion from F to H about 4° 40′; hence the length of that portion of the spectrum on the negative is 64 mm. 1 $\mu\mu$ = 0.72 mm at Hγ

The mechanical parts of the apparatus were constructed by Töpfer of Potsdam, the optical parts by Steinheil of Munich.

The slit is set parallel to the equator and the linear spectrum projected upon the plate is broadened thus: the driving clock is allowed to run a little fast and the star is at uniform intervals brought back to its first position by the slow motion in R. A.

PLATE XV.



The Potsdam Spectrograph.

The careful attention of the observer is required during the exposure. Owing to changes of refraction etc., the declination slow-motion also needs to be occasionally turned. By turning either slow motion in the wrong direction, the star might be lost from the slit and the plate perhaps be spoiled.

Still it is in practice not necessary that the observer view star and slit continuously through the telescope F; if the driving clock is in good order, he will need to look in only at intervals of two or three minutes to see if adjustment in either co-ordinate is required.

A breadth of spectrum of about 0.3 mm was found most suitable for subsequent measurement under the microscope micrometer.

A cylindric lens was wholly dispensed with,—not being employed either in photographing, measuring, or enlarging the spectra.

The arrangement for producing comparison spectra is of great importance in an instrument designed for obtaining displacements of the spectral lines.

Very thin Geissier tubes containing hydrogen were used in nearly all cases.

The tube is placed in the cone of rays from the object-glass, at right-angles both to the optical axis and to the slit, at a distance of 40 cm from the latter. The light falling upon the slit may be therefore considered as diffused and the slit as a source; hence the rays of $H\gamma$ will emerge parallel from the collimator.

It is very important that the slit should be fully and uniformly illuminated by the tube.

This is readily secured by this plan, and the loss of star-light due to the intervention of the tube amounts to but 17 per cent. Even if the tube should lack several degrees of being at right-angles to the slit, the latter will be still fully illuminated, so that a very careful adjustment in this respect is not necessary.

In the method employed by some observers of reflecting the comparison light in at the side, the tube being set parallel to the slit, there is great danger that the comparison rays will not be precisely symmetrical with the axis of the collimator, and a slight error in this respect may result in a spurious displacement greater than the actual effect of the motion of the star in the line of sight.

It may not be without interest to describe the mode of making the adjustments which I have for convenience called "permanent."

The adjustment of the collimator so that it shall lie in the optical axis of the refractor is effected by placing over the collimator-objective a collar carrying a disk of ground glass upon which concentric circles have been etched.

The object-glass of the telescope, having been stopped down to a small aperture, is directed towards the center of the Sun's disk. The diaphragm in front of the slit is turned so that the circular aperture (about 1 mm in diameter) falls at the center of the slit. A bright circular spot will then be formed on the ground glass, and the adjusting screws may be turned until it is concentric with the circle most nearly of its own diameter.

This adjustment, which could be so readily controlled, was found to require alteration but once during a period of three years.

The slit was adjusted in the focal plane of the collimating lens by viewing bright stars through a powerful eye-piece containing blue glass, and then moving the slit and eye-piece back and forth until the edges of the slit and the star images were equally sharp.

This adjustment having been once accomplished at a medium temperature, the slit was rigidly and permanently fastened to the collimator tube, subsequent variations of temperature being compensated for by the adjustment of the camera-objective.

The slit is set parallel with the equator by allowing a star to run along its edge, while the observer views it through the telescope F, the Geissler tube having been set in action to illuminate it. The width of the slit was generally kept constant at 0.02 mm during the investigations made with this instrument. It should be mentioned that during the progress of the spectrographic researches at Potsdam, the spectrograph was only rarely removed from the equatorial.

The adjustments which are necessary for each observation are required by the changes of temperature, which affect chiefly the optical parts of the instrument, the consequences of the expansion of the brass or steel portions being relatively slight. The adjustment of the slit in the focal plane for Hγ of the object-glass of the refractor is an important one. A series of photographs of the spectrum of a bright star is made (with driving clock running correctly, so that the breadth is as small as possible) at different settings of the collimator, and that setting is adopted at which the "node"* of the spectrum falls at the Hγ

* Professor Keeler has aptly described the appearance of such a linear spectrum, obtained with a refractor corrected for the visual rays, as that of a vibrating rod (or string), with its (two) nodes and loops.

line. This process is repeated at various temperatures so that finally a table is made giving the proper setting of the collimator for the argument temperature.

It is desirable that this temperature should be read not only at the spectrograph but also near the object-glass of the refractor.

The adjustment of the photographic film in the focal plane of the camera-objective is effected, as already stated, solely by moving the lens itself. A series of photographs of the solar spectrum at slightly different settings will show what setting is the proper one at the given temperature, and here too a table is constructed giving the proper reading of the head of the screw for various temperatures. Neglect of these two adjustments will result in indistinctness of the spectra, and indeed sometimes in a spurious doubling of the lines.

The effect of different temperatures upon the resulting spectra is somewhat complicated, and mention should perhaps be made of the method of compensating for it in the subsequent micrometric measurement of the negatives. The change in the size of the image on the plate, due to the altered focal length of the camera objective, will be uniformly distributed over the whole image. Not so, however, the effect of the altered dispersion of the prisms; hence the combined result is that two spectra even of the same object taken at considerably different temperatures are neither identical nor geometrically similar. The best procedure is to reduce all the measurements to one single position of the camera lens for a standard temperature at which a good negative of the solar spectrum has been obtained. A curve or table for transforming the micrometer distances into wave-lengths is made from measures of a selected series of standard lines on the solar negative. The solar negative is then laid, film down, upon that of the star so that the lines of one spectrum shall form approximately the continuation of those of the others, thus furnishing a means of identifying those of the standard lines which are present in the star. All the lines of the stellar negative, or of a portion of it, are then carefully measured, the standard ones being specially designated. The reduction to the standard solar negative is now obtained for different portions of the spectrum, say for the two ends and the middle, by comparing the measured distances between identical lines in the stellar and solar spectra. If the standard lines were selected sufficiently close together, this correction will be so small that it may be without further reduction simply added to the tabular quantities which serve in interpolating the wave-lengths of the unknown lines lying between the standard ones. If the star belongs to a spectral type in which very few lines can be identified with standard lines of the solar negatives, the reduction is more difficult, and where greater accuracy is required a comparison spectrum of iron or cadmium should be photographed with the star.

When brilliant spark spectra are employed a small portion of the middle of the slit should be covered (by using the proper aperture in the diaphragm) during the short interval necessary to secure the impression of the comparison spectrum in order that the artificial lines may not hide the finer lines of the star.

According to the experience at Potsdam it is not desirable to prolong the exposure for spectra which are to be used for measures of displacement much over an hour or an hour and a half. In longer exposures elements of uncertainty will be introduced due to changes of temperature, of refraction, and of the instrument's position (however stable it may be).

An exposure of one hour was generally employed, and the faintest star included in the catalogue of motions of 51 stars in the line of sight is of magnitude 2.5.

Another spectrograph, similar to the one above described, has been more recently added to the equipment at Potsdam. It has but one prism and the dispersion is something like one-third of that of the other. This permits fainter objects to be observed (the writer has secured with it spectra of stars of the fifth magnitude), but on the other hand it makes the linear displacement correspondingly less so that the accuracy of measurements of velocities is necessarily much diminished.

A spectrograph very similar to the one first described has been constructed by Töpfer for the Pulkowa Observatory, where it is applied to the great refractor, and in the able hands of M. Belopolsky it may be expected to be of efficient service.

Dartmouth College,
Hanover, N. H., Dec. 22, 1892.

ON THE USE OF THE CONCAVE GRATING FOR THE STUDY OF STELLAR SPECTRA.*

HENRY CREW.

During the summer of 1892 I had the opportunity of using a deep concave grating with the 12-inch and 36-inch refractors of the Lick Observatory. While handicapped in some directions this

* Communicated by the author.

combination of grating and large refractor offers such manifest advantages in others, that I here give some of my meager experience with it in the hope that some one who has such a grating may find in the method all that it apparently promises.

The grating* employed had a radius of 22 inches and was ruled with 2886 lines to the inch.

The mounting was a wooden one designed and made on the spot, the same in principle as that of Professor Rowland, except that for the carriages which take the grating and eye-piece respectively, were substituted slides, which could be fixed at any point of the "beam" with screw clamps. The wooden frame of the instrument was covered with black cloth, and the whole, thus constituting a camera, was mounted, upon two heavy rods, on the eye end of the equatorial, in such a manner that it could slide up and down along the optical axis of the telescope.

A neat plate holder which Mr. Burnham made from a cigar box and the lid of a blacking box completed the outfit.

The adjustments were as follows:

(1.) Collimation was obtained by making the image of the object glass central on the ruled space of the grating.

(2.) Center of curvature, parallelism of slit and rulings, and the other grating adjustments made as usual with sunlight.

(3.) The slit in the photograph was placed in the photographic focus of the refractor by the following method which was suggested to me by Mr. Barnard: a very small plate-holder was made to fit easily over the slit plate. This holder carried a narrow strip of a "*Seed 26*" plate.

In various positions of the spectroscope along the optical axis the plate was exposed to a suitable star (β Cygni is an excellent one) for a second at a time, the photographic plate being slightly displaced across the slit between each exposure.

By an examination of the series of photographs thus obtained one can pick out the focus of maximum sensibility.

The instrument being adjusted the most difficult part remained, viz., to follow the star accurately. For this purpose I found the following method convenient.

One side of the camera was hinged so that it would open and shut after the manner of a bellows.

A hole, cut in this swinging part, enabled one to observe through it (whatever order of spectrum might be used), the direct reflection from the slit.

But when the slit is in the so-called actinic focus, it is at some

* Mr. Brashear very kindly presented this grating to the Lick Obsesvatory.

distance from the apex of any cone of visible rays. This apex is, of course, the visual focus. The slit is, therefore, covered by a portion of the concave wave-surface of the visual rays and we have all the conditions necessary for diffraction through a single opening. The diffraction bands thus produced are *reflected* from the surface of the grating and are easily seen by the naked eye.

Not only so but they are very sensitive to any motion of the star across the slit-plate. One sees immediately whether the star is moving up and down the slit or across it. At the same time, one detects the *sense* of the displacement and corrects it with the slow motions.

The breadth of the central bright band, or the distance between its next door neighbors, serves to determine the width of the slit.

The ruled rectangle on the grating makes a neat background on which a small amount of asymmetry in the distribution of diffraction bands is made evident.

With this arrangement and this mode of following, a number of very fair photographs were obtained.

For instance, two or three of α Cygni and one of Arcturus showing twenty or more lines between *w. l.* 4100 and *w. l.* 4600.

With stars of the *First Type*, and third order of the grating, one gets uniformly the hydrogen lines *F*, $H\gamma$, *h* and *H* all on one plate, but the extremities are not in good focus.

The image of the spectrum band on the negative has about the same shape as a longitudinal section of a marlin spike, owing to the steepness of the color curve.

I was disappointed in not reducing the time of exposure to less than forty minutes, even with the thirty-six-inch glass. "Seed 26" plates were used.

This may have been due to bad focus at the slit, possibly to temperature changes in the tube. No adjustment was considered satisfactory that did not show at least 5 lines between H and K in the solar spectrum. The separation of H and K in the fourth order was $\frac{1}{30}$ of an inch.

At any rate, I never succeeded in getting any proportionality between the intensity of the negative and the time of exposure.

All told, I had but a few nights at my disposal and never found the source of the trouble.

Among the valuable features of the concave grating for this purpose is its astigmatism. These spectra measure from $\frac{1}{32}$ to $\frac{1}{16}$ of an inch in width, so that one can never mistake an ordinary defect in the negative for a line.

Another advantage is that these spectra are normal, being superior in this respect to both prism and plane grating. This fact may prove useful in the identification of lines in the ultra-violet.

Thirdly, the amount of light lost by reflection and absorption in the lenses of the ordinary spectrometer may be a very uncertain and variable quantity. But whatever it be, it is certainly all saved in the use of the concave grating.

On the other hand, one labors under the great disadvantage incident to all gratings of not being able to use but a small fraction of the light which actually passes through the slit.

The method is, therefore, for the present at least, limited to the brighter stars, except possibly some of the Wolf-Rayet type which, while faint to the eye, may have their light so concentrated in various parts of the spectrum as to be quite within the reach of the grating. It is almost needless to add that such a grating deserves a good mounting in metal and should be used on a refractor corrected for the photographic rays, or better still, on a reflector.

Indeed, it appears that that the astronomical world is only just beginning to realize its indebtedness to Rowland for this instrument at once so beautiful and powerful.

NORTHWESTERN UNIVERSITY,
Evanston, Ill., Jan. 7, 1893.

THE HYDROGEN LINE H_β IN THE SPECTRUM OF NOVA AURIGÆ AND IN THE SPECTRUM OF VACUUM TUBES.*

VICTOR SCHUMANN.

The Hydrogen line H_β, as is well known, appears double in the spectrum of Nova Aurigæ, and, at times, these components are divided into still others. The cause of this division of H_β is at present a mystery. The hypothesis that in the spectrum of the Nova one has to deal with the light of a double star appears insufficient to explain all the variations which H_β, in this case, has shown. It is clear, however, from the paper of Dr. and Mrs. Huggins, that if one makes this supposition the basis of all his reasoning, he will have to assume, for the explanation of the case where H_β is not one dark line but three, (observation of Miss Maury, of Cambridge, U. S. A.), not simply one double star but a system of six bodies. Such a hazardous supposition, whatever the interaction of the six bodies, could scarcely be seriously considered in the interpretation of the spectrum of the Nova.

* Communicated by the author.

The fact that the assumption of two stars moving in the line of sight has proved itself insufficient to explain the original appearance, and still less the later developments, of H_β in this spectrum, starts the question as to whether the hydrogen spectrum from terrestrial sources of light may not furnish a more satisfactory explanation. The question becomes more important in consideration of the fact that one can scarcely pass judgment upon stellar processes as revealed by the spectroscope with that certainty with which he interprets spectrosçopic observations in the laboratory. Once assumed that it is possible to simulate with all its anomalies, or even with some of them, the spectrum of the Nova in the laboratory, the supposition of several bodies is no longer necessary; and the simpler explanation of new stars given by Zöllner in 1865* demands our consideration.

The literature of the hydrogen spectrum produced by artificial sources offers us little material for the interpretation of the case in hand. We have indeed some remarkably good measurements of wave-lengths in the hydrogen spectrum, but what is known of the behavior of hydrogen under various conditions of pressure and temperature is, in quantity, meagre, and in quality far below the standard reached by modern apparatus in other departments of spectroscopy.

Most of the observations in this field are of an old date and faulty, at least, on account of the inferior instrumental equipment of that time. What most interests the physical astronomer in the interpretation of stellar spectra, (in so far at least as they depend upon cosmical processes), are the changes of the spectrum produced by changes of pressure and temperature at the luminous source. The position of any line in the spectrum and its wave-length are matters of secondary importance.

During a series of years which I have devoted to the spectrum of the hydrogen tube, this dearth of literature induced me to carefully preserve all the results of my observations which might in any way extend our knowledge of the metamorphosis of this spectrum. I now find on my hands considerable new material relating to the subject. In order to compare earlier and later results extending over a period of years I have used the photographic method; and I have spared no pains to make my instrumental equipment the best of its kind. I have put a special emphasis upon the definition of the photograph. This was the more necessary as small dispersion had to be retained while other and more severe conditions were to be fulfilled.

* *Zollner*, Photometrische Untersuchungen, Leipzig, 1865.

A part of this work refers to the reversal of the hydrogen lines. Experimental work in this direction is beset with difficulties, always great, at times insurmountable. So that I am free to confess that the results of my study of reversals, though they have occupied much time, fall far short of my expectations. And this is why I have not hitherto published anything on this subject. Since, however, certain of these phenomena remind one very forcibly of the changes in the lines of the spectra of Nova Aurigæ, I have decided to describe these phenomena of reversal without waiting to further verify or extend the results already obtained.

I may perhaps indulge the hope that my communication will arouse some interest and incite further rsearch in this field.

I pass now to the description of the experiments mentioned above. The following account is based upon two large series of photographed spectra and upon my photographic diary which contains definite information concerning each spectrum. My experiments refer to the influence of pressure and temperature upon the spectrum of the hydrogen tube. Circumstances were so arranged that the pressure in the tube never exceeded 100 mm. of mercury. The increase of temperature in the electric spark was obtained by the successive introduction into the circuit of a Leyden jar and a spark gap.

The apparatus was put together as follows:

The *Geissler-pump* was connected with one of Kipp's hydrogen generators and with the vacuum-tube whose spectrum was to be photographed. Every part of the apparatus which came in contact with the hydrogen was made of glass with the exception of a quartz stopper to be mentioned later. All the connections, by careful grinding, were made air-tight. The air-pump was filled with mercury which was chemically pure, and the drying tube with phosphoric anhydride spread out upon glass wool.

The *hydrogen* was prepared from the purest obtainable zinc and sulphuric acid, such as are used in regular medical practice, and before being admitted to the drying tube was purified by being passed in series through caustic soda, silver sulphate, (silver nitrate is absolutely worthless for this purpose) and potassium hydrate in stick form. The drying tube consisted of two chambers shut off by stop cocks from the rest of the apparatus and from each other. The hydrogen, after remaining for considerable time (generally over night) in the first chamber, was passed into the second chamber made of two U tubes, and after a still longer delay here, was admitted to the Geissler tube. The drying substance of both chambers (phosphoric anhydride) was spread upon loose fibrous glass wool of purest quality, in such a manner as to expose a large surface. (The ordinary wool of commerce cannot be recommended for this purpose). In this manner hydrogen can be dried more thoroughly than in any other way. If one simply passes the gas over the drying substance several days will be required for it to reach its maximum dryness. Moist hydrogen always gives the spectrum of water-vapor in addition to that of hydrogen, if not in the visible region, at least in the ultra-violet, being, as is well known, especially strong in the neighborhood of w. l., 3000. Angström's units. When, therefore, the visible spectrum is free from foreign lines, one cannot conclude that the contents of his tube are pure. Indeed many impurities make their appearance higher up in the spectrum than the most refrangible of the hydrogen lines. Among these impurities is water-vapor.

The *vacuum-tube* was arranged "end on," and, to secure perfect transparency for the ultra-violet rays, was closed at one end with a conical quartz stopper 3 cm. in length. The capillary part of the tube lay in the geometrical axis of the stopper. The ends of the quartz stopper were plane, parallel, and perpendicular to the axis of the cone. For three-fourths of its length the stopper was carefully ground and fitted to the neck of the tube. The outer half of the cone was given a thin coating of grease. By this method one had nothing to fear from decomposition products of the grease rendering the contents of the tube impure, because the inner part of the stopper remains free from tallow. In like manner the joints of the air-pump and the hydrogen generator were made air-tight. Some tubes so fitted with quartz stoppers cannot be heated by a flame placed underneath. But with the above arrangement one runs no risk of breaking the tube by heating provided he does not bring the flame too near, and in no case up to, the quartz stopper. The tubes were filled, in the usual manner, after each exposure. They were not, of course, sealed off in the flame, but during the whole experiment remained in connection with the air-pump.

The *spectrograph* consisted of a 60° compound prism made up of a right and a left handed quartz together with two plano-convex quartz lenses. The focal length of these lenses for the D line was 750 mm. The capillary portion of the vacuum-tube lay in the prolongation of the axis of the collimator. Between the tube and the collimator was placed a condensing lens made up of two crossed quartz cylinder lenses. This stretched the luminous point out into a line, concentrated the light in the opening of the slit, and above all aided in good definition in the spectrum. Further details concerning the photographic outfit are reserved for the future, since they are aside from the present purpose of this paper.

The *photographic plates* I prepared myself. Those on the market are unsuitable, not being sufficiently sensitive in the F region. All plates intended for use in the neighborhood of the F line demand a strong silver iodide emulsion. A good proportion is 100 parts of silver bromide to 5 parts of silver iodide. Though it is not to be forgotten that such emulsions are valuable only when the silver haloids (Ag Br and Ag I) are deposited at the same time in the gelatine solution. A mixture of prepared silver bromide gelatine and prepared silver iodide gelatine shows very different properties from the above-mentioned emulsion, and is useless for work in the region of the F line. The preparation of this emulsion is best made according to the "silberoxydammonmethode" of Dr. J. M. Eder of Vienna.

The electrical apparatus was composed of a Grove battery of six cells, a Ruhmkorff induction coil giving a 25 cm. spark, a Leyden jar with an outer coating of 500 cm.^{2}, and a spark-holder. In general the strength of the primary current was 15 ampèrès, the electromotive force being 9 volts.

The following results were taken from two series of photographs. The one includes negatives taken under a pressure of 1, 2, 3, 5, 7, 10, 14, 19, 25, 32, 40, 50, 65, 80, 100 mm. of mercury respectively; the other series was made under identical circumstances, except that the respective pressures were 1½, 5, 9, 16, 30, 40, 100 mm. of mercury. The tubes, however, in the two cases were different. The tubes in the first series had the ordinary diameter of Geissler tubes, but the bore of the tubes in the second series was much smaller, amounting to not more than 0.27 mm. For each pressure at least two negatives were made, one with a Leyden jar in circuit, the other with a Leyden jar and a spark gap. Besides these those of several pairs of negatives were taken with the Leyden jar left out of the circuit, but with the spark gap retained. The two series include 57 negatives. All the details of these photographs do not here concern us. I limit myself to the mention of those of their spectral peculiarities which bear upon the subject of this paper. The introduction of the Leyden jar into the circuit increases the photographic energy of the light from the tube, but only up to a certain pressure. As soon as the pressure has reached a few millimeters the photographic effect begins to diminish, the spectrum gradually loses its great wealth of lines, until, at a pressure of 32 mm. only the two lines *H_γ and *H_δ are left, and even these are exceedingly weak and thin. From there on the negatives gain in intensity with increasing pressure, but the linear character of the spectrum does not return. It consists now only of the lines H_β H_γ H_δ and of these the first is the last to make its appearance. At a pressure of 100 mm., H_ε is added. On all the negatives there is a continuous band beginning with H_γ and extending far into the ultra-violet. The photographs of these series taken under low pressures are unimportant for our purpose. I pass therefore directly to the spectra exhibited under pressures of 65, 80, and 100 mm. pressure. Under a pressure of 65 mm. the prominent lines are H_β and H_γ. In these negatives they are well defined, although the sharpness of their edges is injuriously affected by broad, hazy fringes of considerable intensity, which shade off into the background from both sides of the lines.

Under a pressure of 80 mm., H_β has lost much of its definition, and close to it on each side one observes two fine thin lines; the fringe is here present also, only it is wider than under a pressure of 65 mm. H_γ has lost its definition completely but has increased in breadth. The same is true only in a still higher degree of its fringe. Under 100 mm. pressure the more refrangible component of the pair of lines just mentioned as belonging to H_β has disappeared, and in its place has appeared H_β itself, broad, but very weak; near by on the lower side one observes a thin line twice as broad, perhaps, as the thin line of the previous photograph. The fringe of H_β has now spread itself out more toward the blue than towards the red, thus displacing the middle of it towards the blue. In like manner the pair above mentioned appears displaced somewhat towards the opposite side. H_γ remains only as a very weak line which gradually loses itself in the broad, hazy background in which it lies. H_δ possesses still less character than H_γ, and H_ε, which here appears for the first time, is only a faint maximum in the intensity of the spectrum at this place. All the more refrangible hydrogen lines observed in the spectra of the white stars do not make their appearance in photographs made under a pressure greater than 32 mm. In their stead one finds only the continuous spectrum mentioned above.

From this summary it is evident that it is H_β only that shows reversal as well as displacement. In none of the other lines do I

* The subscripts of these two letters are wanting in the author's manuscript. Judging from the next two or three sentences, these subscripts were intended to be γ and δ respectively, and I have accordingly supplied them.—*Translator.*

find any trace of such a change in their appearance. On account of the difficulty of photographing H_α I have devoted no attention to it, though from my earlier observations I found it to be more easily and conspicuously reversed than H.*

If beside the Leyden jar one introduces a spark gap into the circuit, the effect of the jar is so altered that the maximum of photographic intensity which previously made its appearance under a pressure of 32 mm, now appears under a pressure of 2 mm. In fact all the variations of the spectrum produced by the Leyden jar without any spark gap, and under increasing pressure, are now obtained under a pressure of approximately 30 mm less. The only marked deviation from this rule which I noticed was under a pressure of 65 mm, where, as well as under 80 mm, the spectrum shows two fine transparent lines on both sides of the uncommonly faint H_β. No displacement of H_β was here observable. This makes the displacement under 100 mm pressure all the more striking. H_β now appears, in contrast to previous negatives, only as a double line. The more refrangible of its components is very deep [*intensiv*], much widened, and notably displaced towards the blue. The other component, on the contrary, is thin, by no means so widened as the first mentioned line, and very slightly displaced towards the red. H_γ appears on this negative as scarcely more than a slight increase of intensity in the spectral band, which extends farther than usual into the ultra-violet, and overpowers the two very faint maxima of intensity which, when the tube is illuminated for only an instant, one observes in the positions of H_δ and H_ε respectively.

But my experiments with narrower discharge tubes have led to quite different results. In these tubes, as is well known, the temperature is higher than in those of the larger calibre, because the energy of the electric spark is distributed to a smaller number of molecules. To obtain the reversals mentioned above, it occurred to me that this very circumstance would furnish a convenient means of obtaining a high temperature in the vacuum-tube, and it appeared not unlikely that this would favor the reversal of the hydrogen lines. This hope, however, has not been realized, either in this case or in any other, in which I have had the same object in view. The cause of this lies probably in the properties which narrow capillary tubes exhibit when submitted to a powerful electric discharge. If one simply passes the induction spark through a hydrogen tube whose capillary part is

* Here again the subscript is wanting in the author's manuscript. H_β is probably the line intended.—*Translator.*

quite fine, say a quarter of a millimeter, he obtains a very bright hydrogen spectrum. But so soon as a Leyden jar is introduced into the circuit, the brightness of the hydrogen lines diminishes in a very striking manner; and the capillary portion of the tube, which before shone with a red light, flashes out with an intensely bright white light, while at the same time the hydrogen spectrum is replaced by the spectrum of the vapor of glass furnished by the inner wall of the tube. This spectrum of glass contains a great many lines. If we employ a still higher electro-motive-force, as can easily be done by introducing into the circuit a spark-gap, the capillary portion of the tube then shines with a brilliant white light. From the evidence furnished by its spectrum this radiation is entirely from the vapor of glass. The hydrogen spectrum does not make its appearance, and the conduction of electricity is entirely carried on by the vaporized constituents of the glass, with the exception of sodium, which, like hydrogen, appears to take no part in the process. We may remark incidentally that the spectrum of the vapor of glass is one of magnificent colors and very sharp lines. As the discharge current becomes stronger the lines widen, and when the strength of the discharge is still further increased the spectrum becomes continuous, with its maximum of photographic energy in the ultra-violet.

Thus the narrower of my two tubes showed only a trace of reversal in any of the spectra photographed with it. Of course by a pressure of 100 mm. the spectrum as photographed was only a dense continuous band in which one recognized H_β and H_γ as faint lines, together with a number of lines which do not belong to the spectrum of hydrogen.

So far as reversals are concerned, the experiments with the narrow tube need not be mentioned here. Indeed, I have mentioned them merely to indicate what a tremendous influence an apparently secondary matter may exert upon the reversal of the hydrogen lines.

If it be asked whether the phenomena of reversal as observed in my hydrogen spectra furnish, in themselves, an explanation of the reversal of the lines in the spectrum of Nova Aurigæ, the answer must be decidedly in the negative. At the same time it is possible that a sufficient extension of the observations may lead to a more satisfactory explanation of stellar processes than is possible on any hypothesis hitherto proposed, for "the solitary basis of interpretation of stellar spectra is laboratory work."*

LEIPSIC, 17, December, 1892.

* See this journal, volume for 1892, page 582.

ON THE PROBABILITY OF CHANCE COINCIDENCE OF SOLAR AND TERRESTRIAL PHENOMENA.*

GEORGE E. HALE.

In a paper communicated to the Paris Academy of Sciences in 1887† M. Marchand has compared the solar and magnetic observations made at the Lyons Observatory between May 1, 1885, and Oct. 15, 1886. He concludes that "each of these maxima (of a curve of magnetic intensity) sensibly coincides with the passage of a group of spots or a group of faculæ at its shortest distance from the center of the solar disc." He adds that "there seems to be no relation between the intensity of the perturbations and the diameter of the spots."

The coincidence pointed out is a striking one, and some have come to regard it as expressive of a general law. The purpose of this paper, however, is to inquire whether such coincidence may not be of a purely accidental nature. Dr. Veeder believes that perturbations of terrestrial magnetism are caused by disturbance at the Sun's eastern limb, and he finds spots or faculæ at the places indicated whenever auroras are observed. M. Tacchini, on the contrary, holds that the position of the disturbed region on the solar disc has nothing to do with its effect on terrestrial magnetism.

In the observations of M. Marchand "the faculæ were generally observed up to a considerable distance from the two limbs; it may be concluded that they must have persisted as far as the center, although observation was rarely extended to that point." At present it is an easy matter to photograph faculæ wherever they occur on the solar disc with the spectroheliograph of the Kenwood Observatory. In previous numbers of ASTRONOMY AND ASTRO-PHYSICS I have described the instrument and some of the photographs obtained with it. Suffice it here to say that the faculæ are shown on these photographs to be far more numerous than visual observation or photographs taken with instruments hitherto employed had led us to assume. The great spot zones in the northern and southern hemispheres of the Sun are occupied by large numbers of faculæ, which sometimes extend in almost unbroken belts entirely across the disc.

In the following table are given the results of an examination of 142 photographs of the Sun, obtained on as many different days between Jan. 25, and Dec. 3, 1892, at the Kenwood Observ-

* Communicated by the author. † *Comptes rendus*, t. civ, p. 133.

atory. In successive columns are recorded the number of the plate, the date, and the number of groups of faculæ on the central meridian of the Sun.

Plate No. D.	Date. 1892.	h	No. of Groups of Faculæ on Central Meridian.	Plate No. D.	Date. 1892.	h	No. of Groups of Faculae on Central Meridian.
277	Jan. 25,	3.12	1	752	June 10,	1.29	1
313	Feb. 4,	4.32	1	764	11,	11.26	2
315	6,	10.26	1	776	13,	10.54	2
322	9,	10.02	1	782	14,	11.58	2
336	10,	2.31	1	784	15,	10.37	2
343	11,	11.15	1	791	16,	10.45	1
344	12,	11.37	2	801	17,	2.42	2
351	13,	10.42	2	809	20,	12.33	2
361	15,	11.53	2	818	22,	4.31	0
366	16,	12.14	2	823	24,	5.04	3
370	17,	10.33	1	827	25,	12.05	2
375	Mar. 2,	1.11	1	839	July 5,	12.07	1
378	3,	2.38	2	851	6,	12.04	1
379	8,	3.20	1	858	7,	12.23	1
381	10,	11.52	2	862	8,	10.15	1
383	11,	11.03	2	863	11,	10.08	4
391	12,	11.35	2	874	12,	11.42	1
393	14,	12.51	1	884	13,	12.04	2
395	15,	11.59	2	893	14,	10.23	1
402	21,	12.19	1	907	15,	11.51	1
404	23,	4.08	—	915	16,	10.44	2
410	24,	1.08	1	929	18,	11.07	2
413	27,	11.20	1	934	19,	10.54	1
414	28,	11.56	1	956	21,	11.30	1
416	31,	3.22	1	969	23,	4.01	2
421	Apr. 3,	11.29	1	974	25,	12.48	1
429	6,	10.45	3	987	26,	12.05	0
467	9,	3.34	2	1001	27,	11.26	1
481	10,	3.25	1	1012	28,	12.15	1
487	12,	1.24	2	1013	29,	3.45	—
496	15,	1.23	0	1025	30,	12.50	2
505	18,	2.25	1	1033	Aug. 2,	11.52	1
508	19,	10.36	1	1062	6,	12.15	2
519	21,	9.34	1	1073	11,	11.25	1
524	22,	12.50	2	1098	18,	2.20	1
539	23,	10.57	2	1102	19,	2.11	2
549	25,	3.12	1	1106	20,	10.48	2
555	26,	9.42	2	1115	26,	10.52	2
560	27,	1.32	1	1132	27,	12.04	2
573	29,	12.47	1	1135	29,	3.23	0
577	May 3,	4.41	2	1144	31,	12.37	2
586	4,	12.18	1	1154	Sept. 1,	12.42	2
591	6,	10.20	2	1163	2,	12.56	2
605	7,	10.52	0	1168	3,	11.55	1
613	12,	12.00	0	1177	5,	11.20	1
632	14,	2.45	1	1186	6,	12.26	2
645	16,	10.24	1	1196	8,	4.38	1
649	17,	12.47	1	1201	9,	12.21	2
653	18,	2.02	2	1219	16,	11.00	1
656	21,	10.35	2	1215	15,	3.35	3
687	23,	2.04	1	1227	17,	11.10	1
698	25,	11.09	0	1242	20,	4.08	1
717	26,	2.22	1	1246	22,	11.22	2
730	27,	1.35	1	1253	23,	12.08	2
736	June 4,	11.32	1	1260	24,	12.22	1
743	6,	12.48	1	1270	26,	1.32	1

Plate No. D.	Date. 1892.	No. of Groups of Faculae on Central Meridian.	Plate No. D.	Date. 1892.	No. of Groups of Faculae on Central Meridian.
	h			h	
1275	Sept. 27, 11.12	1	1423	Oct. 19, 12.55	1
1285	28, 11.44	0	1429	25, 10.09	1
1299	29, 1.02	1	1439	27, 2.48	1
1313	30, 2.40	1	1444	28, 10.14	2
1317	Oct. 3, 10.51	2	1456	29, 11.54	2
1329	4, 1.25	1	1467	Nov. 5, 12.48	1
1339	5, 11.44	1	1472	10, 11.21	1
1342	7, 10.40	1	1480	12, 9.45	1
1351	10, 10.44	1	1503	15, 12.49	1
1365	11, 10.18	1	1511	16, 10.23	1
1376	12, 10.00	1	1529	18, 12.16	2
1393	13, 2.50	2	1538	19, 1.10	1
1395	14, 12.14	2	1542	21, 11.45	1
1404	15, 1.02	1	1549	26, 2.41	1
1411	17, 12.57	1	1551	Dec. 3, 10.36	1

It will be seen that out of the total number of 142 plates 132 show one or more groups of faculæ on the central meridian, *i. e.*, at their shortest distances from the center of the solar disc. Of the remaining 10 plates 8 have no faculæ on the central meridian, and 2 are doubtful. If we class the doubtful plates with those showing no faculæ in the position indicated, we find a probability of 0.93 that at a given time there will be one or more groups of faculæ on the central meridian.* Moreover, as the number of groups of faculæ is independent of the heliocentric longitude of the Earth, it follows from the observations employed that the probability that at a given time one or more groups of faculæ will be on a given meridian of the Sun is 0.93. This value will naturally be smaller in periods of decreased solar activity, but coincidences noted in epochs like the present can hardly be regarded as of great importance. The very fact that both eastern limb and central meridian advocates can find coincidences sufficiently numerous for their purpose, is strong evidence that chance alone may be involved. A 27-day period in terrestrial magnetism, however, would seem to mean that the solar rotation is an important factor.

Lord Kelvin has recently shown the extreme difficulty of regarding terrestrial magnetic storms as due to the direct magnetic action of the Sun. Instead of discouraging further research the utterances of so distinguished an authority should lead to a more careful study of solar phenomena, and a fuller consideration of the electrical forces possibly at work in our central luminary.

BROOKLYN, Jan. 11, 1892.

* The mean number of groups on the central meridian per day may be taken as a rough measure of the solar activity. Averaged for months we find for February 1.4, March 1.3, April 1.4, May 1.1, June 1.6, July 1.3, August 1.5, September 1.4, October 1.3, November 1.1. There was thus a maximum in June, and after August a steady decline.

STARS HAVING PECULIAR SPECTRA.*

M. FLEMING.

An examination of the photographs of stellar spectra received on December 6, 1892, from the Peruvian station of the Harvard College Observatory, and taken under the direction of Professor W. H. Pickering, has led to the discovery of the following objects of interest. The five stars given in the following table have spectra of the fifth type, consisting mainly of bright lines. This adds two more to the group of stars of this class in the constellation Argo, and increases the known number of these objects in the entire sky from forty-five to fifty, all of which are near the central line of the Milky Way. None of these five stars are catalogue stars. Their approximate right ascensions and declinations for 1900 are given, followed by their galactic longitudes and galactic latitudes.

R. A. 1900		Decl. 1900		G. Long.		G. Lat.	
h	m	°	′	°	′	°	′
10	13.3	−57	24	251	14	−0	48
10	47.9	−61	46	257	5	−2	36
11	55.2	−54	33	263	29	+6	53
13	24.3	−61	34	275	15	−0	1
15	55.0	−62	28	290	34	−8	28

In addition to the objects in the above list, a star in Scorpius, whose approximate position for 1900 is in R. A. 16^h 56^m.8 Dec. —36° 40′, was found to have the hydrogen lines bright in its photographic spectrum. As this is a property of many known variables of long period and has already led to the discovery of a number of new variables, chart plates containing the region of this star were at once examined and resulted in the confirmation of its variability. The plate on which the star was found was taken in August 1892. The exact date is not given since the record has not yet been received from Peru. The magnitudes < 12.9 12.4, < 11.4, < 11.4, 9.5. < 10.4, 11.3, 11.8, 11.3, 12.6, < 11.2, 10.5, 10.5, 10.4, 10.1, < 11.4, < 11.4, and 9.2 were derived from measures of photographs taken on June 3, June 21, July 9, July 13, 1889; March 25, May 9, June 14, June 21, June 23, Sept. 5, Sept. 6, 1890; May 18. May 18, May 20, May 20, 1891; May 17, May 17, and August, 1892, respectively. From an examination of spectrum plates taken at Cambridge B. D. + 9° 4369, R. A. 19^h 56^m.3, Dec. + 9° 14′ (1900) magn. 8.7, is shown to have a spectrum of the fourth type.

HARVARD COLLEGE OBSERVATORY,
Cambridge, Mass., Jan. 11, 1893.

* Communicated by Edward C. Pickering, Director of the Harvard College Observatory.

ASTRO-PHYSICAL NOTES.

All articles and correspondence relating to spectroscopy and other subjects properly included in ASTRO-PHYSICS, should be addressed to George E. Hale, Kenwood Observatory of the University of Chicago, Chicago, U. S. A. Authors of papers are requested to refer to last page for information in regard to illustrations, reprint copies, etc.

The Ultra-Violet Hydrogen Spectrum.—In a recent letter, Professor W. H. Pickering writes, "In looking over the October number of ASTRONOMY AND ASTRO-PHYSICS, I see that in the article by M. Deslandres, he supposes that the five hydrogen lines he refers to are new. All of them are found in the stellar spectra, and have been known for some years. He will find four of them referred to in the Draper Catalogue, p. 6. Two more beyond the five he mentions were found here last year in the photographic spectrum of Canopus, which have been accordingly designated as o and π. These more refrangible lines are not found, as might be supposed, in the bluest stars, but in those that are much more yellow. Thus the last line of the hydrogen series in the Orion stars is ι (iota), and the same is true of Sirius, which, by the way, is not a particularly blue star. Canopus, which contains the most complete series of hydrogen lines so far known, is of the second type, but rather bluer than our Sun. M. Deslandres' paper is interesting as giving further proof that the temperature of the prominences is probably higher than that of the solar surface."

Photography of Sun-Spot Spectra.—The spectra of Sun-spots have recently been photographed in the less refrangible region by Father Sidgreaves at Stonyhurst, and in the blue, violet and ultra-violet by Professor Young and Professor Hale. In a recent letter, Father Sidgreaves says: "The remarks I should make upon these plates (in region D — *b*) are precisely those Professor Hale has made in ASTRO-PHYSICS upon the spectra in the more refrangible end: intensified absorption, but no clear evidence of widening." Doubt is thus thrown on the reality of the widening of lines as an objective phenomenon, but that it occurs in certain cases cannot be controverted. If the effect were a subjective one, we should expect to find all the lines of the solar spectrum more or less widened in spots, but in reality certain lines appear to be widened, while others cross the dark absorption band without apparent change. In any case the photographic method should certainly prove far superior to the visual in studies of spot-spectra.

In a discussion of Father Sidgreaves' photographs at the November meeting of the Royal Astronomical Society, Capt. Abney said that he had made many photographs of Sun-spots and their spectra, and had come to the conclusion that there is really no widening of the dark lines over spots. The appearance of widening in the photographs he considers simply due to the fact that the plate is there less exposed.

Since the above note was written we have learned from Professor Young that he has obtained photographs which clearly show widened lines in the green region of the spectrum.

Schumann's Photographs of the Ultra-Violet Spectrum.—We have recently received through the kindness of Herr Victor Schumann, of Leipsic, two of his original negatives of the extreme ultra-violet spectrum. They were taken with his vacuum-spectrograph, the optical parts of which consist of a 70° fluor-spar prism and two fluor-spar lenses of 120 mm. focal length. The sensitive plates were made by Herr Schumann after his own formula, which gives the only plates yet obtained which are sensitive to the region above λ 1852.

Plate No. 2832 (Oct. 15, 1891), was exposed for one minute to the spark taken between aluminium electrodes, placed at a distance of 1 mm. from the slit. The spectrograph was exhausted to a pressure of 1 mm. of mercury. Four groups of strong lines are shown above λ 1852, all of which were previously unknown.

Plate No. 2889 (Oct. 26, 1891) greatly extends our knowledge of the spectrum of hydrogen. The vacuum-tube was in open connection with the interior of the spectrograph, so that the same pressure (3 mm. of mercury) existed in both. The extremely narrow slit (0.010 mm.) made necessary an exposure of 48 minutes. A strong group of lines is shown at λ 1620, and beyond this a very large number of fainter lines.

The definition and sharpness of the lines in these photographs surpasses anything we have ever seen. In the microscope the plates are seen to be free from grain, while but little of the sharpness is lost under great magnification. After a visit to Herr Schumann's laboratory and a careful study of his apparatus and methods, we have come to regard him as without an equal in experimental spectroscopy.

A Criticism by M. Faye.—It will be remembered that at the last summer's meeting of the British Association, Professor Schuster propounded in his Presidential Address before Section A, a number of suggestive questions in regard to the nature of the Sun and its spots. In *Comptes rendus*, Dec. 5, 1892, M. Faye recalls these remarks, and criticises them in the light of his well-known theory of the Sun.

M. Faye admits, as he has had occasion to do in consideration of the facts many times before, that the penumbra of a spot but very rarely shows any indication of cyclonic motion. But he adds that this by no means proves "that the gases enclosed in the umbra do not rotate, for the penumbra is a phenomenon wholly exterior to the spot; it can only exceptionally be affected by the gyration."

M. Faye's idea of the plan and section of a normal Sun-spot is given in a figure accompanying his paper. The cyclone is supposed to penetrate vertically through the lower strata of the photosphere, at the same time producing a considerable fall of temperature in its immediate vicinity. The small luminous clouds, formed at the extremity of ascending columns of vapor, and constituting the photosphere, exist at a lower level in the cooler region surrounding the spot, and are drawn out into the familiar filaments of the penumbra. The comparatively cool mass of gas through which we see the penumbra causes the decreased brilliancy by its absorption.

Thus the penumbra exists at a lower level and surrounds the cyclone at a distance. It therefore does not, in general, participate in its rotatory motion.

In support of his views, M. Faye presents an analogy drawn from a study of terrestrial cyclones. Meteorologists can hardly be said to accept unanimously M. Faye's theories of the latter phenomena, but in carrying out the parallel, the immobility of the cooled mass of air surrounding a cyclone is accounted for by the same reasoning employed in the case of spot-penumbræ.

In regard to Professor Schuster's suggestion that, as cyclones in a group should move around each other in a definite way, we ought to obtain decisive evidence for or against the cyclone theory by a close study of the relative positions of a group of spots, M. Faye admits the difficulty of accounting for the various appearances of a large spot in process of disintegration. He maintains, however, that there is always a tendency in the various parts toward circular motion, and again seeks support in terrestrial analogies.

Professor Schuster's somewhat cautious proposal that the spots be regarded as regions of the solar surface cooled by artificial evaporation due to electric discharges setting out from within the photosphere is not acceptable to M. Faye, on account of the difficulty of believing that a discharge could persist in the same place for months in a mobile and fluctuating medium.

M. Faye considers it possible that the violent movements at the surface of the Sun may cause slight disturbances of terrestrial magnetism, but sees no reason to modify our ideas on the purely mechanical origin of spots, pores and prominences or their periodicity.

Remodeling the Paris Reflector for Spectroscopic Work.—In No. 20, T. CXV, o the *Comptes rendus*, M. Deslandres describes the changes which he has made in the four-foot reflector of the Paris Observatory in order to adapt it to stellar spectrum photography, with special reference to the determination of motions in the the line of sight. The diagonal reflector of the Newtonian mounting has been removed, and a spectroscope is supported inside the tube of the telescope, with the collimator in the axis of the tube, and the slit in the focal plane of the great mirror. Three prisms of heavy flint glass give the necessary dispersion. Their dimensions, and those of the collimator, are not stated, but the linear scale of the photographs is such that in the blue part of the spectrum a displacement of one two-hundredth of a millimeter corresponds to a motion of 3.6 kilometres in the line of sight. According to these figures, one millimeter on the photographic plate is about equal to 11.7 tenth-metres at F, so that the scale is considerably larger than that of the Potsdam photographs, (1 mm = 13.0 tenth-metres at Hγ). The spectrograph is enclosed in a box of sheet steel, in order to ensure the perfect rigidity of all the parts.

In order to keep the image of a star on the slit during long exposures, the polished steel slit-plate is slightly inclined, and light reflected from it is received in a four-inch telescope with diagonal eye-piece, placed near the lower end of the great tube within easy reach of the slow motions in right ascension and declination.

This arrangement of a spectroscope directly in the axis of a reflecting telescope is rendered possible by the great size of the mirror which M. Deslandres has at his disposal. It is evidently a very efficient one, and we may expect the Paris reflector to take a more prominent part in future astronomical work than it has occupied in the past.

According to M. Deslandres, exposures of two hours can be made with this apparatus without detriment to the definition. This brings fourth magnitude stars within the range of the instrument. Seventy measureable photographs of stellar spectra were obtained during the first ten months of the present year.

The advantages of these photographs, as compared with those obtained at Potsdam, are stated to be the following:

"(1). The emergent beams from the star and from the source of comparison are as nearly as possible of the same diameter, a condition which is necessary in absolute measurements of displacements, but which is not realized at Potsdam.

"(2). The displacement of the spectra is measured, not by the single ray Hγ, as at Potsdam, but by all the lines of hydrogen, calcium, and iron, which are for the most part fine and sharp in the star and in the comparison source, and which are equally valuable for comparison, since they are united by the telescope in the same focus. The precision of the measurement is, therefore, augmented in a large degree.

"(3). The great surface of the mirror, although it makes the operation more difficult, permits the measurement of the motions of at least 250 of the stars in our sky, while the Potsdam apparatus gives only 60. The stars which surround the constellation Hercules and the region of the sky opposite to it are relatively numerous. They will give, with the telescope, the velocity of translation of the solar system in space, which velocity has not yet been determined."

The Spectrum of β Lyræ.—Herr Belopolsky gives in *A. N.* 3129 the results of some recent photographs of the spectrum of β Lyræ with the new spectrograph of the Pulkowa Observatory. The spectrograph is a duplicate of the one at Potsdam, but it has the advantage of the far greater light-gathering power of the 30-inch refractor. Herr Belopolsky's results confirm those of Pickering, who described in *A. N.* 3051 the main features of the peculiar spectrum of this star; but while Pickering's photographs extend from the upper limit of the violet to only a little below F, and did not admit of absolute measures of wave-lengths, Belopolsky's were made on orthochromatic plates, and extended so far down in the spectrum as to include the D_3 line. They, moreover, allowed the positions of the lines to be determined with accuracy. A translation of Herr Belopolsky's article will be given in our next number.

Recent Observations of Nova Aurigæ.—The new star in Auriga continues to attract a great deal of interest in astronomical centers. A perceptible increase of brightness took place in December, probably in the nebular lines, and certainly in the lower part of its spectrum, as the photographic brightness is now considerably less than the visual. Some doubt has been expressed in Europe as to the reality of the nebulous appearance of the star first reported at the Lick Observatory. Mr. Newall, who was unable to see the nebulosity with the 25-inch refractor at Cambridge, points out that if a star emits D and F light only, its image in the Lick telescope would consist of two stellar points situated on the axis at some distance apart, and that if the eyepiece should be focussed on one of these points, that image would be surrounded by a diluted disc some 7″ in diameter, due to light diverging from the other point. With light of wave-lengths 500 and 575, the false nebulosity produced by chromatic aberration would be 4″ in diameter. While this reasoning is entirely correct, we do not think it probable that the experienced observers on Mt. Hamilton have been deceived by the appearances above referred to. A few experiments with the focussing screw would quickly show whether the nebulosity was real, or merely an effect of chromatic aberration. That such experiments have been made, is evident from Mr. Campbell's article in *A. N.* 3133. Among the interesting points thus brought out, and explained from a consideration of the color curve of the 36-inch refractor, is the fact that a small nebula like Nova Aurigæ will, in general, appear relatively brighter in a small telescope than in a large one. In *A. N.* 3118, Mr. Barnard describes "a faint glow, perhaps half a minute in diameter," which could hardly have been produced by chromatic aberration.

Herr Renz, of Pulkowa, also describes the nebulous aspect of the Nova. Mr. Newall suggests that observations should be made with a large reflector, but up to the present, no such observations appear to have been published. We believe, however, that Mr. Roberts could find no evidence of nebulosity on photographs taken with his reflector.

The region of Nova Aurigæ was photographed on Sept. 25 and 30 by Herr Max Wolf. The nebulosity surrounding the star did not appear on the plates, as the spreading of the photographic image extended beyond the limits of the nebula, but a number of new diffuse nebulæ were discovered in the vicinity of the star, and there even appeared to be traces of nebulous appendages proceeding from the star itself. Unfortunately the weather did not permit sufficiently long exposures to remove all doubt as to their reality.

Mr. Campbell gives an account of his recent spectroscopic observations, and a drawing of the spectrum of the Nova, in *A. N.* 3133. The drawing is the same as that on page 717 of our October number, with the addition of a few faint lines in the violet. Nearly all the lines in the spectrum of the Nova were found either in the planetary nebula Σ 6, (G. C. 4390), or in the great nebula of Orion, and they are represented in many planetary nebulæ that were examined, although with some remarkable differences in the relative intensities of the lines. The wave-length of the chief nebular line in the spectrum of the Nova still continues to increase.

The observations of Herr E. Von Gothard (*A. N.* 3122 and 3129, and the January number of this journal), show the almost complete identity of the spectra of the Nova and the planetary nebulæ, in a very beautiful manner. The novelty of the apparatus with which the photographs were taken is not the least interesting feature of the observations. An object-glass prism of small refracting angle was placed over the end of a 10¼-inch reflector, and the spectra were photographed with an ordinary star camera. As we have already printed a full account of these observations, a further description is unnecessary. Herr Von Gothard's photographs, like those of Mr. Campbell, show that the Nova has a disc of sensible diameter, thus proving the existence of nebulosity around the central star, as described by the Mt. Hamilton and Pulkowa observers. Herr Von Gothard's apparatus was not well adapted to the determination of wave-lengths; hence, no doubt, his mistaken identification of the lowest line in the spectrum of the Nova in the yellow, with a line of the Wolf-Rayet stars at λ 582. According to Mr. Campbell, whose apparatus was capable of giving accurate positions, the line falls about midway between the bright lines in the Wolf-Rayet stars near λ 5814 and λ 5691, and it does not appear in any other spectrum so far examined.

It seems remarkable that no traces of the second nebular line at λ 4958 or of the third line at F appear upon Herr von Gothard's photographs, considering the distinctness with which the chief line is represented in the drawings made from them. The peculiar character of the curve of sensitiveness of an orthochromatic plate may account for the absence of these lines, or it may be that the drawing is not intended to represent relative intensities with any approach to accuracy.

Some of Herr von Gothard's conclusions are not new, but of those that are, one of the most interesting is that the line at λ 3727 is very much brighter in large diffuse nebulæ than in small nebulæ of the planetary type, and the brightness of this line in a great number of different nebulæ would be worthy of investigation. It will be remembered that it was this same line which surprised Dr. Huggins by appearing on some of his photographs of the spectrum of the Orion nebula and being absent from others taken with a slightly different position of the slit. The line was strongest, however, in parts of the nebulæ near the stars of the trapezium, and therefore in regions which were presumably most condensed.

A very complete investigation of the spectrum of Nova Aurigæ with the Pulkowa spectrograph, during the early months of 1892, has been published by Herr A. Belopolsky, in the *Bulletin de l'Academie Imperiale des Sciences de St. Petersbourg*. It deals entirely with the spectrum of the star before its reappearance in

August, and is one of the most valuable contributions to the history of the Nova which has appeared.

No. 26 of the Publications of the Astronomical Society of the Pacific contains, besides many other articles of great interest, an admirable review of the whole spectroscopic history of Nova Aurigæ by Professor Campbell. It is based on the observations made at Mt. Hamilton, and gives all the measurements of lines made before and after the reappearance of the star. A table of the chromosphere lines is given, with numbers proportional to the product of their frequency and intensity, and it is shown that nearly all the prominent lines in the winter spectrum of the star are prominent lines in the chromosphere spectrum, and *vice versa*.

The motion of the star in the line of sight since its reappearance, as deduced from the displacement of the chief nebular line, is exhibited in the following table a part of which was printed in our December number:

Date	λ	Velocity.	Date	λ	Velocity.
1892, Aug. 20	5003.6	− 128 miles	1892, Sept. 22	5002.5	− 169 miles
21	3.7	125	Oct. 12	3.6	128
22	3.7	125	19	3.8	121
23	3.1	147	Nov. 2	4.4	99
30	2.4	173	3	4.7	87
Sept. 3	2.4	173	0	4.4	99
4	1.9	192	16	4.9	80
6	2.1	184	17	4.9	80
7	1.9	192	24	4.5	− 95
15	2.2	− 180			

Disintegration of Holmes' Comet.—Photographs taken by M. Deslandres at Paris, with a small photographic lens of short focus, show that on the 21st of November Holmes' comet was beginning to divide into two parts. On the 10th of December an hour's exposure failed to bring out any trace of the comet. The doubling detected by M. Deslandres was no doubt part of the process of diffusion (and perhaps disintegration) which has been observed of late.

Astronomical Work at Harvard College Observatory in 1892.—The forty-seventh Annual Report of the Director shows that the great activity which has characterized the work of the Harvard College Observatory in the past has been fully maintained in 1892. A mere list of the different objects observed would extend beyond the limits of a note. Some of the more important astro-physical observations made either at Cambridge or at the branch Observatory at Arequipa, Peru, may, however, be mentioned as examples.

In Peru, Mr. Bailey finished the work of observing the southern stars with the meridian photometer. Professor Wm. H. Pickering, in charge of the station, observed the Moon and planets with the thirteen-inch equatorial. Many new double stars were also found. In connection with the Henry Draper memorial nearly two thousand photographs of stellar spectra were taken with the eight-inch Bache telescope, and their examination led to the discovery of many interesting objects. At Cambridge, 2777 photographs of stellar spectra were taken with the eight-inch Draper telescope, and 996 with the eleven-inch telescope. A large proportion of the latter were devoted to the spectra of β Aurigæ and ζ Ursæ Majoris, in order to determine the law of the periodic doubling of the lines. Many photographs of Nova Aurigæ and its spectrum were also made. We note with pleasure that sufficient money has been subscribed by friends of the Observatory to enable Professor Pickering to proceed with the construction of a fireproof building for storing these invaluable photographs.

The report begins with an acknowledgement of the indebtedness of the Observatory in the past to the mechanical skill of the late George B. Clark.

CURRENT CELESTIAL PHENOMENA.

PLANET NOTES FOR MARCH.

H. C. WILSON.

Mercury will be "evening star" during March, and will be visible to the naked eye, an hour after sunset, during the two middle weeks of the month. The planet will be at greatest elongation east from the Sun, 18° 27′, March 14. After this date the planet will move rapidly westward, reaching inferior conjunction on the evening of the last day of the month.

Venus will be "morning star," but very close to the Sun.

Mars will be visible in the west in the early evening. Having passed by Jupiter this planet will have proceeded so far to the eastward that the Moon will overtake it two days later than Jupiter. The conjunction of Mars and the Moon will occur March 21, at $10^h 50^m$ P. M. central time.

Jupiter may be observed best in the twilight during March. After dark he will be to low in the west to be well seen. A conjunction of Jupiter and the Moon will occur March 20, at $2^h 37^m$ A. M. central time. In northern latitudes on the other side of the Earth an occultation of Jupiter will be seen.

Saturn comes to opposition March 29, and so is in excellent position for observation during the greater part of the night. For chart of his position in the sky see our January number, page 80. The rings may be well seen since they make an angle of 8° with the line of sight. There will be two conjunctions of Saturn with the Moon during this month, the first occurring March 4, at $5^h 36^m$ P. M. central time, with Saturn 1° 12′ north of the Moon; the second March 31, at $9^h 24^m$ P. M., Saturn 1° 5′ north of Moon.

Uranus is approaching opposition, and is in good position for observation after midnight. For place in the constellations see January No., p. 80. Uranus will be in conjunction with the Moon, 1° 35′ north, March 7, at $3^h 28^m$ A. M. central time.

Neptune will be in good position for observation during the first half of the night. For his position in Taurus see our December No., p. 937.

Date. 1893.	R. A. h m	Decl. ° ′	Rises. h m	Transits. h m	Sets. h m
			MERCURY.		
Mar. 5	23 59.8	+ 0 12	7 01 A. M.	1 04.8 P. M.	7 09 P. M.
15	0 46.7	+ 7 35	6 39 "	1 12.2 "	7 46 "
25	0 52.7	+ 9 22	5 58 "	12 39.0 "	7 20 "
			VENUS.		
Mar. 5	22 12.8	− 12 23	6 03 A. M.	11 18.1 A. M.	4 33 P. M.
15	23 00.0	− 7 55	5 54 "	11 25.9 "	4 58 "
25	23 46.1	− 3 06	5 41 "	11 32.4 "	5 24 "
			MARS.		
Mar. 5	2 49.0	+ 17 05	8 40 A. M.	3 53.5 P. M.	11 07 P. M.
15	3 15.5	+ 19 00	8 18 "	3 40.6 "	11 03 "
25	3 42.5	+ 20 41	7 58 "	3 28.3 "	10 59 "
			JUPITER.		
Mar. 5	1 36.7	+ 8 57	8 02 A. M.	2 41.3 P. M.	9 20 P. M.
15	1 44.8	+ 9 45	7 28 "	2 10.2 "	8 53 "
25	1 53.5	+ 10 34	6 54 "	1 39.4 "	8 25 "
			SATURN.		
Mar. 5	12 45.4	− 1 59	7 53 P. M.	1 48.3 A. M.	7 44 A. M.
15	12 42.8	− 1 41	7 10 "	1 06.4 "	7 03 "
25	12 40.0	− 1 22	6 26 "	12 24.3 "	6 22 "

Date. 1893.	R. A. h m	Decl. ° ′	Rises. h m	Transits. h m	Sets. h m
		URANUS.			
Mar. 5	14 33.0	− 14 33	10 31 P. M.	3 35.6 A. M.	8 40 A. M.
15	14 32.1	− 14 29	9 51 "	2 55.4 "	8 00 "
25	14 31.0	− 14 23	9 10 "	2 15.0 "	7 20 "
		NEPTUNE.			
Mar. 5	4 28.4	+ 20 14	10 04 A. M.	5 32.7 P. M.	1 01 A. M.
15	4 28.9	+ 20 15	9 25 "	4 53.9 "	12 23 "
25	4 29.6	+ 20 18	8 54 "	4 23.0 "	11 55 P. M.
		THE SUN.			
Mar. 5	23 06.4	− 5 45	6 30 A. M.	12 11.5 P. M.	5 53 P. M.
15	23 43.0	− 1 50	6 11 "	12 08.8 "	6 06 "
25	0 19.6	+ 2 07	5 53 "	12 05.9 "	6 19 "

Configuration of Jupiter's Satellites at 8h p. m. Central Time.

Mar.		Mar.		Mar.	
1	3 1 ○ 2 4	12	4 2 1 ○ 3	23	3 2 ○ 1 4
2	3 2 ○ 1 4	13	♃ 4 2 ○ 3	24	3 1 2 ○ 4
3	3 1 ○ 2 4	14	4 ○ 1 2 3	25	3 ○ 4 1 2
4	○ 3 1 2 4	15	4 1 3 ○ 2	26	♃ 4 1 ○ 3
5	2 ○ 3 4 ●	16	3 2 4 ○ 1	27	4 2 ○ 1 3
6	2 1 ○ 3 4	17	3 1 2 ○ ●	28	4 ○ 2 3 ●
7	○ 1 3 2 4	18	3 ○ 1 2 4	29	♃ 4 1 ○ 2
8	3 1 ○ 2 4	19	1 2 ○ 3 4	30	4 3 2 ○ 1
9	3 2 4 ○ 1	20	2 ○ 1 3 4	31	4 3 1 2 ○
10	4 3 1 ○ ●	21	○ 1 2 3 4		
11	4 3 ○ 1 2	22	1 3 ○ 2 4		

Phenomena of Jupiter's Satellites.

1893.	h m			1893.	h m		
Mar. 1	7 10 P. M.	II	Tr. In.	Mar. 19	6 02 P. M.	II	Sh. Eg.
3	5 38 "	II	Ec. Re.	20	6 26 "	I	Tr. In.
4	6 41 "	III	Ec. Dis.		7 06 "	I	Sh. In.
11	7 12 "	III	Oc. Dis.	21	6 35 "	I	Ec. Re.
12	7 15 "	I	Oc. Dis.	26	6 13 "	II	Sh. In.
13	6 38 "	I	Tr. Eg.	28	5 49 "	I	Oc. Dis.
	7 23 "	I	Sh. Eg.	29	6 35 "	III	Tr. In.
17	7 05 "	II	Oc. Dis.				

Occultations Visible at Washington.

Date 1893.	Star's Name.	Magnitude.	IMMERSION Washington M. T. h m	IMMERSION Angle f'm N pt. °	EMERSION Washington M. T. h m	EMERSION Angle f'm N pt. °	Duration. h m
Mar. 14	B.A.C. 7550	6.3	16 42	48	17 39	281	0 57
21	65 Arietis	6.0	6 42	35	7 36	289	0 54
24	49 Aurigæ	5.7	7 39	51	8 33	324	0 54
25	υ Geminorum	4.3	6 25	47	7 15	335	0 50
26	υ^4 Cancri	5.7	4 44	89	5 59	298	1 15
28	42 Leonis	6.0	5 46	81	6 49	328	1 03

Phases and Aspects of the Moon.

		d	h m
Full Moon	Mar.	2	10 03 A. M.
Apogee	"	8	6 06 P. M.
Last Quarter	"	10	11 14 A. M.
New Moon	"	17	10 34 P. M.
Perigee	"	20	1 06 "
First Quarter	"	24	3 33 "

Minima of Variable Stars of the Algol Type.

U CEPHEI.

R. A. .... $0^h\ 52^m\ 32^s$
Decl. .... $+81°\ 17'$
Period .... $2d\ 11^h\ 50^m$

1893.		
Mar.	1	9 P. M.
	6	9 "
	11	9 "
	16	8 "
	21	8 "
	26	8 "
	31	7 "

ALGOL.

R. A. .... $3^h\ 01^m\ 01^s$
Decl. .... $+40°\ 32'$
Period .... $2d\ 20^h\ 49^m$

Mar.	9	10 P. M.
	12	6 "
	29	11 "

λ TAURI.

R. A. .... $3^h\ 54^m\ 35^s$
Decl. .... $+12°\ 11'$
Period .... $3d\ 22^h\ 52^m$

Mar.	2	11 P. M.
	6	10 "
	10	9 "
	14	8 "
	18	7 "
	22	6 "

R. CANIS MAJORIS.

R. A. .... $7^h\ 14^m\ 30^s$
Decl. .... $-16°\ 11'$
Period .... $1d\ 03^h\ 16^m$

Mar.	6	8 P. M.
	7	11 "
	14	7 "
	15	10 "
	23	9 "
	24	Midn.
	31	8 P. M.

S ANTLIÆ.

R. A. .... $9^h\ 27^m\ 30^s$
Decl. .... $-28°\ 09'$
Period .... $7^h\ 47^m$

Mar.	1	2 A. M.
	2	1 "
	3	12 "
	3	12 P. M.
	4	11 "
	5	10 "
	6	6 A. M.
	6	10 P. M.
	7	5 A. M.
	7	9 P. M.
	8	5 A. M.
	9	4 "
	10	3 "
	11	3 "
	12	2 "
	13	1 "
	14	1 "
	15	12 "
	15	11 P. M.
	16	11 "
	17	10 "
	18	6 A. M.
	18	9 P. M.
	19	5 A. M.
	19	9 P. M.
	20	5 A. M.
	21	4 "
	22	3 "
	23	3 "
	24	2 "
	25	1 "
	26	1 "
	26	midn.
	27	11 P. M.
	28	11 "
	29	10 "
	30	6 A. M.

S ANTLIÆ CONT.

Mar.	30	9 P. M.
	31	5 A. M.

δ LIBRÆ.

R. A. .... $14^h\ 55^m\ 06^s$
Decl. .... $-\ 8°\ 05'$
Period .... $2d\ 7^h\ 51^m$

Mar.	3	4 A. M.
	10	3 "
	17	3 "
	24	3 "
	31	2 "

U CORONÆ.

R. A. .... $15^h\ 13^m\ 43^s$
Decl. .... $+32°\ 03'$
Period .... $3d\ 10^h\ 51^m$

Mar.	3	3 A. M.
	10	1 "
	16	midn.
	23	8 P. M.
	30	6 "

U OPHIUCHI.

R. A. .... $17^h\ 10^m\ 56^s$
Decl. .... $+\ 1°\ 20'$
Period .... $0d\ 20^h\ 8^m$

Mar.	2	5 A. M.
	3	1 "
	7	6 "
	8	2 "
	13	3 "
	18	4 "
	23	5 "
	24	1 "
	28	5 "
	29	1 "

COMET NOTES.

New Outburst of Light in Holmes' Comet.—During the past month Holmes' comet has been very faint. On Jan. 12 it was so faint that with a sixth magnitude star in the field of view the condensation about the nucleus could not be seen with the 16-inch refractor of Goodsell Observatory, although the faint nebulosity of the comet as a whole could just be discerned with the 5 inch finder. On Jan. 16, however, at 8 P. M. central time, we were astonished to find in the place of the nucleus, what looked like a bright planetary nebula of about the seventh magnitude. Finding no nebula put down for that place in Dreyer's catalogue, we tried a micrometer measure of R. A. from a 10 magnitude star about 1′ distant, and in a few minutes detected motion which agreed with that of Holmes' comet. The nucleus was at first very hazy but afterward became more starlike and about as bright as an 8 mag. star. The coma was not more than 30″ in diameter and very bright, almost as bright as when I first saw the comet on Nov. 11. The temperature was so low on that night (14° below zero F.) that we could not safely attempt to put the spectroscope on the telescope.

On Jan. 17, we received telegraphic announcement of the outburst, it having been observed by Palisa at Vienna Jan. 16. On Jan. 18, we again observed the comet and found it still bright. The nucleus was about 8.5 magnitude and more star-like than on the 16th. The coma was fainter than on the 16th but its diameter was more than doubled, >1′, and it was a little elongated in the direction 45°. We could trace also an exceedingly faint tail extending 5′ or more in the direction 45°. In the 5-inch finder the faint nebulosity of the November comet has almost wholly faded out of sight. It looks as if the new Holmes' comet were about to repeat the phenomena of the first, only on a smaller scale because farther away. How this will fit in with Mr. Corrigan's theory is not easy to see.

The ephemeris given below was computed from the elements by Professor Boss (*Astr. Jour.* No. 283) which up to the present time represent the course of the comet very closely. We do not give the column of "Brightness" for it is evidently useless to predict the brightness of such an extraordinary object.

Holmes' Comet.—Holmes' Comet has been observed for position at the Dearborn Observatory on every clear night since the 21st of November. About the middle of December it had become so faint as to be a difficult object for observation with the 18½-inch retractor.

In January the volume had greatly diminished, and the comet appeared as a faint nebula.

On the 14th of January it was observed as a faint, globular nebula about 2′ of arc in diameter.

On the 16th inst., however, instead of a faint diffused nebula, there was seen a beautiful nebulous star of the 8.5 magnitude. The central portion was star-like, and the nebulosity surrounding it was about 10″ of arc in diameter. The remarkable transformation from an attenuated nebula to a nebulous star, therefore, must have taken place some time between the 14th and 16th inst. The comet was observed again on the 18th, when it presented nearly the same appearance as on the previous night, except that the nebulous envelope was somewhat larger. On the 19th the star-like nucleus had expanded to 3″.7, and the envelope was about 7″.6 in diameter.

If the comet would retain its stellar appearance it might be visible in all parts of the orbit as has already been pointed out by Schulhof. G. W. HOUGH.

Northwestern University, Jan. 19, 1893.

Remarkable Transformation of Holmes' Comet.—Holmes' comet had become exceedingly difficult to see and to measure in the 12-inch.

It had enlarged and diffused from its previously bright and well defined condition until at the last observation it was merely a great and feebly luminous mist on the face of the sky. There was a small and very faint condensation which could be seen and bisected only with the greatest care.

On the night of Jan. 16 after a spell of clouds and fog, the sky cleared about dark. At 6:30 I turned the 12-in. on the position of the comet in hope of getting at least one more measure of its position if it could be seen at all. To my astonishment I found in the place of the comet a small, bright, hazy, star-like body. I had used a low power (80) for the purpose of more readily finding the comet. I was familiar enough with this portion of the sky to know that no nebula like this existed there. Several pointings were made to be sure of the position. The place fell exactly where the comet ought to be. There was, however, a nebula close to this position (N.G.C.561) and it might be that object brightened up. To settle whether it was the comet, I began to take differences of right ascension between the object and a star. These soon established beyond doubt that the object really was Holmes' comet. With a magnifying power of 150 it was about $\frac{1}{2}'$ in diameter, round and strongly condensed, but with no tail. Feeble traces of a nucleus could sometimes be made out. In the $3\frac{1}{4}$-inch finder the comet could not be distinguished from a star. It was perfectly stellar and of $7\frac{1}{2}$ or 8 magnitude —comparisons were made with stars in field of view for its light and such will be kept up.

Careful measures were made of the comet's position with the micrometer.

At $8^h\ 10^m$ a setting of the wires gave the diameter $= 29''.4$ my estimate being $30''$. While under observation the comet seemed to be perceptibly brightening. Two more observations for its diameter at $9^h\ 45^m$ gave $32''.4$. At this time the nucleus had developed clearly and was very noticeable as a small, ill-defined star. I am sure the nucleus was actually developing while under observation.

At $10^h\ 0^m$ there was no longer any question but that the comet was getting brighter and the nucleus developing.

An opportunity now offering to observe the comet with the 36-in. I went to that instrument. With 520 diameters the comet was perfectly round and fairly well defined with a bright, hazy, star-like nucleus. The circular disc of light was greenish blue and the nucleus yellowish. The comet was indeed a perfect miniature of the appearance it presented with the 12-inch on Nov. 8th when I first saw it.

I now began a series of measures of the diameter with the micrometer of the 36-in. The definiteness of the outline of the comet may be inferred from the accordance of the following independent measures:

	h	m		$''$
Standard Pacific Time	10	29	diameter =	43 4
	10	30		44.9
	10	31		43.6
	10	42		47.8
	10	43		47.9
	10	45		46.0
	11	13		47.3
	11	15		46 1

Position angle of the wires during the measures $= 70°$.

The measures seem to show that the object was expanding while under observation.

This is certainly the most remarkable comet I have ever seen, taking every thing into consideration.

About 9 o'clock a dispatch came announcing that the outburst had also been observed at Vienna by Palisa. E. E. BARNARD.

Mt. Hamilton, 1893, Jan. 17.

POSTSCRIPT.—Holmes' comet was observed again with the 12-inch on the 17th of January. The principal change to record had occurred in the nucleus. This was now a bright, yellowish star. The coma by contrast or in reality, was fainter, and not distinctly terminated. The comet in appearance resembled a star shining through fog. Everything in this night's view was subordinate to the nucleus which shone out conspicuously. This nucleus was more conspicuous than an 8th magnitude star though it lacked the intensity of a stellar point. In the finder the comet appeared, as a whole, possibly a little brighter than on the 16th. It now looked like a small, bright, hazy star.

With 150 the nebulosity was so indefinitely terminated that only a rude guess of its diameter could be made. One setting of the wires gave diameter 46″.

There is no question but that I had actually watched the development of the nucleus on the 16th, or if it had existed previously, the unveiling of it had been observed.

When I first saw the comet on the 16th there were only the feeblest suspicions of a nucleus, the comet being very strongly condensed. By 9 o'clock, or a little before, a faint star-like nucleus had begun to show; from this time on it became clearer and brighter until the comet was too near the horizon to see. On the 17th the nucleus had eclipsed everything else.

The observations of the 17th were confined to the 12-inch.

Jan. 18.—The nucleus to-night has faded wonderfully. It is just distinguishable—about 13 mag. The comet is somewhat larger. There is a rather rapid brightening in the center in which the taint nucleus can occasionally be made out.

Mt. Hamilton, Jan. 18, 1893. E. E. BARNARD.

The Recent Phenomena of Holmes' Comet.—The remarkable phenomena which have been recently observed in Holmes' comet favor in a high degree, the hypothesis that this body is the result of a collison between two asteroids. The first effects of such a collision would be to expand the volume of the resultant body, some of the matter whereof would be thrown entirely beyond the sphere of attraction due to the mass of said body. This matter, thus diffusing in space, appeared as the rapidly expanding nebulous envelope seen shortly after the discovery of the comet. But, probably, the greater portion of the matter did not pass beyond the sphere of attraction, and if so it must have fallen back toward the centre of gravity of the mass. As expansion and separation of the matter diminished the brightness of the nucleus, so must the contraction above described have increased the brilliancy thereof, producing the effect recently observed.

Furthermore, the fall of this matter must have generated heat, and another vaporous envelope similar in many respects to that produced by the original collision. In fact, under this hypothesis, we should expect several such alterations in the light, and in the dimensions of the body. The heat generated by the fall of matter has also probably increased the brightness of the nucleus, and the spectroscope will probably throw much light on this point. Another phenomenon which would naturally result from such a collision, would be the rotation of the resultant mass; for unless the centres of inertia of the original asteroids, and the point of impact, were in the same straight line, a condition which is possible but quite improbable, axial rotation must have resulted and such rotation, it is very obvious, might produce variations in the light of the nucleus.

Furthermore, the rotation of such a mass of debris, as it were, would cause internal collisions which would result in heating and expanding the mass.

To one or all of these causes we may, I think, reasonably attribute the recent remarkable phenomena displayed by Holmes' comet.

St. Paul, Minn., Jan. 21, 1893. SEVERINUS J. CORRIGAN.

Holmes' Comet—Its Probable Relation to the Zone of Asteroids.—The mean distance of this body is 3.58—less than that of Thule or either of several asteroids on the outskirts of the zone; its period is 2480 days, also less than those of some minor planets; the inclination of its orbit to the plane of the ecliptic is 20°, less than that of many asteroids. The eccentricity is almost the same with that of Æthra, the 132d asteroid; the aphelion is within the orbit of Jupiter; the perihelion distance is 2.17, or less than those of several minor planets. It becomes, therefore, a question whether Holmes discovered a comet or a planet. The question as to its origin is one well worthy of consideration. If the groups of asteroids had separate common origins may not reunions or collisions be also possible? Such collisions, however, on account of the small masses and the relatively slow motions would not be violent.

The result of observation and discussion in this new field of research will be looked for with interest by all astronomers. DANIEL KIRKWOOD.

Ephemeris of Comet 1892 III (Holmes).

[Computed by H. C. Wilson and A. G. Sivaslian from Boss' Elements, *Astr. Jour.* 283].

Gr. Midn.		App. R. A. h	m	s	App. Decl. °	′	″	log r	log Δ
Feb.	2	1	45	43.6	+ 33	49	34	0.4332	0.4228
	4	1	48	44.3	33	52	23		
	6	1	51	47.2	33	55	28	0.4357	0.4431
	8	1	54	52.4	33	58	50		
	10	1	57	59.7	34	02	27	0.4382	0.4529
	12	2	01	09.1	34	06	18		
	14	2	04	20.5	34	10	22	0.4407	0.4529
	16	2	07	33.8	34	14	39		
	18	2	10	48.9	34	19	09	0.4432	0.4624
	20	2	14	05.8	34	23	49		
	22	2	17	24.4	34	28	38	0.4457	0.4717
	24	2	20	44.6	34	33	36		
	26	2	24	06.4	34	38	42	0.4482	0.4807
	28	2	27	29.6	34	43	54		
Mar.	2	2	30	54.3	34	49	13	0.4507	0.4894
	4	2	34	20.3	34	44	37		
	6	2	37	47.5	35	00	05	0.4532	0.4979
	8	2	41	16.0	35	08	38		
	10	2	44	45.8	35	11	14	0.4556	0.5061
	12	2	48	16.7	35	16	51		
	14	2	51	48.9	35	22	30	0.4581	0.5141
	16	2	55	22.1	35	28	11		
	18	2	58	56.2	35	33	51	0.4605	0.5217
	20	3	02	31.4	35	39	31		
	22	3	06	07.6	35	45	11	0.4630	0.5301
	24	3	09	44.7	35	50	48		
	26	3	13	22.7	+ 35	56	21	0.4654	0.5363

New Elements of Comet 1892 III (Holmes).—M. Schulhof in *Astr. Nach.* 3140 gives the following elements of comet Holmes, derived from observations Nov. 9, 15, 21, 25, Dec. 9 and 13:

$$
\begin{aligned}
\text{Epoch} &= 1892,\ \text{Dec. } 13.5,\ \text{Paris M. T.} \\
M &= 26^\circ\ 08'\ 33''.8 \\
\pi &= 345\ \ 53\ \ 12\ .2 \\
\Omega &= 331\ \ 42\ \ 12\ .1 \\
i &= 20\ \ 47\ \ 22\ .9 \\
\varphi &= 24\ \ 13\ \ 12\ .6 \\
\mu &= 513''.548 \\
\log a &= 0.559617 \\
T &= 1892\ \text{June } 13.2379\ \text{Paris M. T.} \\
\text{Period} &= 6.909\ \text{years.}
\end{aligned}
$$

(M, π, Ω, i: Mean equinox 1892.0)

These elements agree closely with those of Professor Boss (*Astr. Jour.* No. 283) and represent the observations very exactly. They are doubtless very near the true elements of the orbit.

M. Schulhof calls attention to the fact that the orbit of Holmes' comet resembles that of De Vico, 1844 I. The criterion of Tisserand

$$n = \frac{1}{a} + \frac{2\sqrt{Aj}}{Rj^2}\sqrt{p}\cos i,$$

in which n is constant through all modifications of the orbit by a single disturbing body, is quite completely satisfied.

	n	π °	Ω °	i °	e	a	lj °
Comet Holmes	0.532	345	332	21	0.41	3.63	149
Comet de Vico 1678	0.542	323	163	3	0.63	3.07	143
Comet de Vico 1844 I	0.537	343	64	3	0.62	3.10	163

Comet 1892 I (Swift) is still visible with a 16 inch telescope. It is faint round, 30″ in diameter, with a slight condensation in the center. Miss F. Gertrude Wentworth's elements of the orbit (*Astr. Jour.* No. 273) represent the observations closely. On Jan. 16, the corrections to the ephemeris were + 1ˢ in R. A. and — 1.6′ in Decl.

Ephemeris of Comet 1892 I (Swift).

[Computed from Miss Wentworth's elements (*Astr. Jour.* No 273) by H. C. Wilson and Miss C. R. Willard].

Gr. M. T. 1893.	App. R. A. h m s	App. Decl. ° ′ ″	log r	log Δ	Br.
Feb. 5.5	0 40 45.8	+ 25 23 50	0.62277	0.65664	0.004
9.5	44 34.6	22 43	0.62702	0.66558	
13.5	48 25.3	23 03	0.63121	0.67419	.004
17.5	52 17.7	24 44	0.63534	0.68248	
21.5	0 56 11.4	27 40	0.63943	0.69074	.004
25.5	1 00 05.8	31 42	0.64346	0.69808	
Mar. 1.5	04 01.8	36 45	0.64745	0.70539	.003
5.5	07 56 2	42 48	0.65138	0.71238	
9.5	1 11 51.6	+ 25 49 43	0.65527	0.71906	0.003

Ephemeris of Comet 1892 II (Denning).

[From *Astr. Nach.* 3140].

Berlin M. T. 1893	App. R. A. h m s	App. Decl. ° ′	log r	log Δ	Br.
Feb. 5.5	4 04 53	− 17 35.6	0.5630	0.5345	0.15
9.5	04 29	17 30.6			
13.5	04 24	17 24.7	0.5711	0.5570	0.13
17.5	04 37	17 18.0			
21.5	05 08	17 10.8	0.5791	0.5781	0.12
25.5	05 54	17 03.3			
Mar. 1.5	06 56	16 55 7	0.5870	0.5979	0.10
5.5	08 11	16 48.3			
9.5	09 39	16 40.8	0.5947	0.6163	0.09
13.5	11 16	16 33.7			
17.5	13 07	16 27.2	0.6023	0.6333	0.08
21.5	15 07	16 21.2			
25.5	17 16	16 15.9	0.6098	0.6489	0.07
29.5	4 19 33	− 16 11.2			

Ephemeris of Comet 1892 IV (Brooks Aug. 28).

(From *Astr. Nach.* No. 3131.)

1893	App. R. A. h m s	App. Decl. °	log r	log Δ	Br.
Mar. 1	18 06 02	− 38 44.9	0.1586	0.1504	5.53
2	07 54	36.4			
3	09 44	27.8			
4	11 30	19.3			
5	13 13	10.7	0.1723	0.1534	5.12

		R. A. h	m	s	Decl. °	′	log. r	log Δ	Br.
Mar.	6	18	14	53	− 38	02.1			
	7		16	30	37	53.5			
	8		18	04		44.9			
	9		19	34		36.3	0.1859	0.1559	4.75
	10		21	01		27.7			
	11		22	25		19.2			
	12		23	46		10.6			
	13		25	04	37	02.1	0.1992	0.1578	4.43
	14		26	19	36	53.5			
	15		27	31		45.0			
	16		28	40		36.4			
	17		29	47		27.9	0.2122	0.1591	4.15
	18		30	50		19.4			
	19		31	51		11.0			
	20		32	48	36	02.5			
	21		33	42	35	54.0	0.2249	0.1599	3.90
	22		34	33		45.7			
	23		35	20		37.4			
	24		36	05		29.1			
	25		36	47		20.8	0.2373	0.1602	3.68
	26		37	26		12.5			
	27		38	02	35	04.2			
	28		38	35	34	55.9			
	29		39	06		47.7	0.2494	8.1602	3.48
	30		39	33		39.6			
	31		39	57		31.5			
Apr.	1		40	18		23.4			
	2		40	36		15.5	0.2613	0.1599	3.30
	3		40	52		07.7			
	4		41	06	34	00.1			
	5		41	18	33	52.7			
	6	18	41	27	− 33	45.4	0.2728	0.1597	3.13

Comet 1893 I (Brooks, Nov. 18.)—This comet is an easy one to observe with a small telescope. Its motion has been quite rapid. Since Dec. 23, it has been above the circle of perpetual visibility, but it is now going rapidly south. The elements which appear to best represent the observations thus far are the following by M. P. Maitre in *Astr. Nach.* 3138. The ephemeris which follows was computed by Mr. A. G. Sivaslian from these elements.

ELEMENTS OF COMET 1893 I.

$$T = 1893 \text{ Jan. } 6.5355 \text{ Paris M. T.}$$

$$\left.\begin{aligned} \omega &= 85^\circ\ 15'\ 05''.4 \\ \Omega &= 185\ \ 39\ \ 05\ .6 \\ i &= 143\ \ 52\ \ 16\ .4 \end{aligned}\right\} 1892.0$$

$$\log q = 0.077328$$

Ephemeris of Comet 1893 I (Brooks Nov. 19).

Gr. M. T.		R. A. h	m	s	Decl. °	′	log r	log Δ	Br.
Feb.	5.5	0	03	50	+ 32	17.6	0.1084	0.1483	1.78
	6.5		05	55	31	40.1			
	7.5		07	55	31	04.2			
	8.5		09	49	30	29.8			
	9.5		11	39	29	56.9	0.1164	0.1834	1.47
	10.5		13	25	29	25.4			
	11.5		15	06	28	55.1			
	12.5		16	44	28	26.1			
	13.5		18	19	27	18.3	0.1250	0.2154	1.22

Gr. M. T.	R. A.	Decl	log r	log Δ	
	h m s	° ′			
Mar. 14.5	0 19 51	+ 27 31.6			
15.5	21 20	27 05.9			
16.5	22 47	26 41.2			
17.5	24 11	26 17.5	0.1340	0.2446	1.02
18.5	25 33	25 54.7			
19.5	26 52	25 32.7			
20.5	28 09	25 11.5			
21.5	29 25	24 51.2	0.1436	0.2713	0.86
22.5	30 39	24 31.5			
23.5	31 50	24 12.5			
24.5	33 00	23 54.2			
25.5	34 09	23 36.6	0.1534	0.2956	0.74
26.5	35 17	23 19.5			
27.5	36 23	23 03.0			
28.5	37 28	22 47.0			
Mar. 1.5	0 38 32	+ 22 31.6	0.1635	0.3178	0.64

New Minor Planets 1892 S, T, U and V.—These were all discovered by photography in December, the first three on plates exposed by Charlois at Nice and the last by Wolf at Heidelberg.

	Photograph.				First Observation.		
1892	By	At	Date.	Mag.	Gr. M. T.	R. A.	Decl.
					h m	h m s	° ′ ″
S	Charlois	Nice	Dec. 8	13 5	Dec. 10 7 22.2	4 34 10.7	+ 27 23 18
T	Charlois	Nice	Dec. 9-10	10.0	Dec 11 7 04.8	4 54 14.3	+ 31 37 48
U	Charlois	Nice	Dec 14	12.0	Dec. 15 6 46.7	4 47 32.5	+ 12 15 40
V	Wolf	Heidelberg	Dec. 16-18	11.5	Dec. 20 9 46.0	5 49 43 2	− 29 23 34

NEWS AND NOTES.

In this number bills will be found for renewal of subscription for the year 1893, for such as have not already done so. It is very desirable that the publisher be notified promptly whether or not subscribers desire the continuance of this journal for the year 1893. For information see "Publishers' Notices" at the end of this number. Foreign subscribers will please notice a small increase in price to cover postage occasioned by recent increase of size to be maintained in the future.

The French Academy of Sciences honors E. E. Barnard with the Lalande Gold Medal.—At the meeting of the Academy of Sciences of France held December 19, 1892, E. E. Barnard of Lick Observatory was honored by the award of the gold medal for his astronomical discoveries, especially for his recent discovery of the fifth satellite of Jupiter. This new member of the Jupiter system was found last September by the aid of the great telescope at Mt. Hamilton. It has since been seen by some smaller instruments in this country, viz., the refractors at the University of Virginia, Princeton and Evanston, but it is much the faintest, and the most difficult body known in the solar system, and probably it would not have been discovered with a less powerful telescope. The smallest instrument with which it has yet been seen is 18½ inches aperture, the Clark refractor of Dearborn Observatory.

It may be of interest to some of our readers to know that the Lalande medal is given only to original discoverers and investigators in astronomical fields, and it is probably the highest recognition of merit from the learned societies in the world. It has only been given to experienced astronomers when some great discovery has been made. In 1890 this prize was awarded to Schiaparelli of the Royal Observatory of Milan, for his observations determining the rotation time of Mercury and Venus. Mr. Barnard's new satellite of Jupiter has been regarded in this country and in Europe as the most brilliant discovery of the age. The readers of this journal generally know that Mr. Barnard stands at the head in comet discoveries in the world, and that he was first to discover a comet by the aid of photography. His ability as an astronomer is also recognized by the fact that several of the leading observatories of the country are anxiously ready to give him place, if he cares to consider their offers.

Harvard College Observatory, Arequipa, South America.—In a private letter under date of Nov. 29, Professor W. H. Pickering writes of his absence from Arequipa in the interior of South America, for the purpose of latitude and longitude determinations. He has also measured the height of some of the principal mountains, presumably the highest on the continent.

In speaking of the October number of this publication Professor Pickering comments quite at length on the article by M. Deslandres, and expresses great pleasure in its perusal.

Since his return to Arequipa he speaks of being busily engaged with observations upon the rotation of Jupiter's first and second satellites, and with observations on the planet itself. In connection with his study of the satellites he already suggests some new things that he promises to speak of soon in a communication to this periodical.

Double-Star Orbits Recently Computed by Glasenapp.—Professor Glasenapp is continuing his investigation of the orbits of binary stars. He has recently published (*A. N.* 3119) the orbits of β 883 (period 16.35 years), 8 Sextantis, discovered by Alvan Clark (period 93.92 years), and φ Ursæ Majoris (period 115.4 years). The last named is OΣ 208. He has also recomputed the orbit of β Delphini (β 151), using the recent measures of this rapid system, which will soon be published.

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85 Pegasi.—Prof. Glasenapp has recently recomputed the orbit of this interesting binary (β 733) and reduces the period to 17.48 years. This pair was discovered with the Chicago 18½-inch in 1878. It is a difficult pair at all times, as the components are very unequal, and the maximum distance is only 0″.8. All of the positions are by Burnham and Schiaparelli, with the exception of three sets of measures by Hall. The elements were calculated in 1889 by Schaeberle, and a period of 22.3 years found. It has been measured each year at Mt. Hamilton since that time, giving data for a more accurate result. The observed and computed positions agree remarkably well in Glasenapp's orbit, and the error in the periodic time may be assumed to be a small one. There are but five binaries known with periods of less than twenty years, OΣ 535, β 989, β 883, β 733 and ξ Sagittarii. The period of the last named pair is not altogether certain. Celoria found 16 years for β 151, but this has been shown to be too short.

Double Star Measures by Leavenworth, 1892.—Professor F. P. Leavenworth has recently published in the *Astronomical Journal* his last micrometrical measures of double stars at the Haverford College Observatory. The measures were all made in the first half of 1892 with the 10-inch equatorial. The list of stars comprises about 90 pairs, the majority of them being β stars, for which there are no recent measures.

Western Union Time;—The unreliability of the Western Union Time service, so-called, for railway companies and jewelers is being shown more and more the longer it is tried. Recently the clock controlled by this telegraph company on Washington time, as it is claimed, has been ordered out of the Union Depôt at Duluth because the Superintendent of this Depot claimed that the time was unreliable. The same thing has been repeatedly reported in the publications from other prominent cities in the United States.

The telegraph company assumes to distribute the standard time of the Naval Observatory at Washington to all points in the United States for the use of railroad companies and commercial business generally, at certain prices named by such company. This time is obtained directly or indirectly through a certain clock company in New York, and the telegraph company therefore uses the clocks manufactured by that company only. For a similar reason the Western Union Company will use time from Washington only. At least Washington time only is claimed to be used. This matter has been tested somewhat. The time of local observations has been offered to the telegraph company free of charge and such offers have been refused. It certainly would be more convenient for the telegraph company to use local Observatory time that necessarily goes into its general offices from the wires of railroad companies that take the time of local observatories and do not patronize the Western Union time. But the company has refused to take the local Observatory time when offered free of charge. Now, why is this? Plain enough when the whole plan of this business is understood. It is not because Washington time does not cost anything. It is not because the best time service is cared for by the telegraph company. It is not because the best controlled clocks are offered to its patrons, for the contracting parties had better ones in their possession when this time distribution began. What is the root of the matter? The present administration of this Government is about to change, and it is a good time for the friends of Colleges and local Observatories to understand the detailed history of this Western Union deal, and to see if some egregious wrongs can not be righted, even though it makes some officials in high places at Washington a little uncomfortably warm.

Position of Nova Aurigæ for Nov. 1892, by Barnard.—In *Monthly Notices* for Nov. 1892, Prof. Barnard has a paper on Nova Aurigæ, giving a brief account of his discovery of the nebulous character of this star in August last, and the results of his measures of the companion stars in the field. These stars were carefully measured by Burnham shortly after the discovery of the variable. The agreement generally is very close, but Barnard makes the distance of E about a quarter of a second greater, which would seem to imply some proper motion on the part of the faint companion.

Motion of Σ 2525.—Mr. Burnham published a paper on the motion of Σ 2525 in *Monthly Notices* for December 1891, giving all of the measures of this pair down to that time, with a graphical representation of the relative change. Mr. J. E. Gore has used these observations, together with a later set of measures made with the Lick telescope in 1892, to compute the orbit by the Glasenapp method, (*Monthly Notices*, Nov. 1892) and finds a period of 138.54 years. He places the smaller component in the fourth quadrant. It is a difficult pair, the distance now being only $0''.2$.

J. M. Schaeberle of Lick Observatory planned to start for South America Jan. 25 to observe the total eclipse of the Sun, April 15–16.

γ **Coronæ Australis.**—Professor Sellors, of the Government Observatory at Sydney, contributes a new orbit of γ Coronæ Australis to the last number of *Monthly Notices*. Using all the measures down to and including 1891, he finds a period of 121.24 years. Gore, with the same range of measures, gave a very different result (*Monthly Notices*, May, 1892), his period being 154.41 years. In the last ten years no less than four other orbits have been computed, with periods varying from 55 to 93 years. It is difficult to account for these wide discrepancies, as this is a very easy pair at all times, and the measures should be of the highest accuracy. It is evident that for some time to come, careful observations are much more important than new elements.

New Director for Haverford College Observatory.—Professor W. H. Collins has succeeded Professor F. P. Leavenworth as Director of the Haverford College Observatory. The latter resigned last summer to take the chair of astronomy in the University of Minnesota. Professor Collins will continue the double star work which he has been engaged in for several years past under the former director.

New Nebula.—Professor Swift writes in the August number of ASTRONOMY AND ASTRO-PHYSICS about a new nebula independently picked up by Professor Barnard and myself in α, $3^h\ 56^m\ 20^s$; $\delta + 69°\ 30'$ (1890), and about two degrees S. E. of the star Gamma Camelopardi. He claims to have seen this nebula many years ago with his 4½-inch comet-seeker. My purpose now is not, however, to discuss the question as to priority of discovery but to mention that, while comet-seeking on August 19 last, I was surprised to find another new nebula not far distant from the one before alluded to. It is rather faint, with nucleus about 12th magnitude, and very small, but it was sufficiently conspicuous to be discovered with a power of 40 only on my 10-inch reflector. The position of the nebula is

$$\alpha\ 3^h\ 36^m\ 15^s,\ \delta + 67°\ 45'\ (1890).$$

My determination of the place is not likely to be very accurate as I have no good observations of the comparison stars. A small nebula discovered by Professor Swift, No. 1469 of the New General Catalogue, lies in the region closely contiguous, for it is only 1¼ degrees E. N. E. of the new object.

Bristol, England, Jan. 1, 1893. W. F. DENNING.

The Telescope of the Future.—When in 1825 the Dorpat refractor of 9½-inches aperture was constructed, it was considered a masterpiece, writes Alvan G. Clark in the *North American Review*, and it was considered the limit had been reached. Guinard, however, had made better glass possible, and Fraunhofer better workmanship. As a consequence there were constructed in 1845 two object glasses of 15 inches aperture. But this limit was again surpassed when we succeeded in procuring discs for an 18¾-inch glass, which were figured and sent to Chicago. Then followed the 26-inch lenses of the Washington and McCormick Observatories, the 30-inch of the Pulkowa, and finally the great 36-inch lens of the Lick Observatory.

It must be remembered that the ground had been disputed inch by inch, and that with each succeeding advance the limit of successful glass melting was thought to have been attained. Even quite recently a noted optician, speaking of the possibility of obtaining discs larger than 36 inches, said it appeared to him that the chances of obtaining 40-inch discs in the present state of the art were remote. And yet there are now in my manufactory two remarkably fine discs of 40 inches diameter ready for figuring.

Who then shall set the limit to this phase of the art considering the great possibilities of scientific improvement and advance of the present day, in view of what has been already accomplished?

Students' Work at the Underwood Observatory. The Underwood Observatory, in connection with Lawrence University at Appleton, Wis., was fully equipped for work at the opening of the present College year. The outfit consists of a ten-inch Clark equatorial, a four-inch meridian circle, a mean time and a sidereal clock, a sidereal chronometer, a chronograph, a spectroscope and filar position micrometer. A local time service has been established in connection with the Observatory.

The Observatory work is elective, and restricted to the Senior class in order that the number be sufficiently small to give each student plenty of time with the instruments.

During the present term, two lines of work are being pursued, viz. ,time and double-stars. For this work the class is divided into groups of twos, one group working with the meridian circle and one with the equatorial each night; by this arrangement, each member of the class has four nights per week with the instruments, two nights with the equatorial and two with the meridian circle.

Each student is required to determine the sidereal time by his own observations, convert the same into mean solar time and determine the error of the mean time clock, which error is not allowed to reach a single second.

In double star work each student makes a catalogue of all stars observed, the data contained being the R. A., Dec., Position Angle and Distance.

They are held to a star until they can not only measure it twice alike, but do it correctly. L. W. UNDERWOOD.

Planisphere by M. W. Harrington.—Recently Professor M. W. Harrington, formerly director of the Observatory at Ann Arbor, and now Chief of the Weather Bureau, Washington, D. C., has prepared a movable planisphere showing the constellations and the principal stars in each, conveniently related by lines to assist in tracing them. The old mythological figures have been omitted. The names of the bright stars are given, those having less magnitude are indicated by the Greek letters in the usual way, while the faintest are shown by dots in their proper places without designation, including some stars of the fourth magnitude. The printing is white on dark blue paper, securely mounted on heavy board. The circular card is a little more than ten inches in diameter and turns on a central pivot so that it may be set to any hour of the night, and the principal naked-eye features of the sky are in order before the observer's eye. It is an excellent device for self-instruction in regard to the places and names of easy celestial objects that any student or teacher might easily know, if only disposed to spend half-hours occasionally looking at the evening sky with this planisphere in hand as an inexpensive and a ready guide.

This planisphere has an important feature that we have not seen in others with which we are acquainted, and that is, a means of identifying the planets. Upon its reverse side tables are given with easy directions, so that the planets, Mercury, Venus, Mars, Jupiter, Saturn and Uranus, can be found when visible to the unaided eye.

The publishers of this planisphere are The Register Publishing Company of Ann Arbor, Michigan. Attention is called to the advertisement elsewhere given.

C. H. Rockwell, of Tarrytown, N. Y., is to spend a portion of the winter in California.

The Astronomical and Physical Society of Toronto.—At its last meeting in 1892 of the Astronomical and Physical Society of Toronto, the attendance was large. A communication was read from Mr. Maunder, of Greenwich, England, in which favorable mention of Flammarion's recent publication on Mars was made; a letter from M. L. Niesten of Berlin in regard to the globes of Mars that he makes; also from Dr. M. A. Veeder on Auroræ. Under the head of predictions for the first part of January a very complete list of useful current phenomena was named. The annual meeting of the Society was to be held on 10th January, 1893.

The title of the paper for the evening was "Before the Beginning," and was read by John A. Paterson. It consisted of a review of the nebular theory by La-Place, with references to Dr. Morrison's illustration, Dr. Croll's theory, and the changeful state of the stuff of which the visible universe is made, in the process of time, with some speculation as to the condition of it prior to the date of the beginning of the La Place theory. The place given to the collision theory is possibly too prominent, if the brief review of the paper which we have seen is just.

BOOK NOTICES.

Introductory to Modern Geometry of Point, Ray, and Circle. By William Benjamin Smith, Professor of Mathematics and Astronomy, University of the State of Missouri. New York: Messrs. Macmillan & Co, publishers, 1893.

Only a cursory examination of the subject matter of this new book shows that it is written for a very practical purpose, with the aim to present in a simple form, a body of geometric doctrine that should be a standard for admission to college, and a knowledge of which is required of Freshmen for entrance to the University of the State of Missouri. In its preparation the author, in carrying out his aim, has had reference both to the amount and the kind of matter to be introduced. Whether he is right in either of these important particulars is a grave question now already before the minds of the best mathematicians and teachers of higher education in this country. The movement set on foot a few months ago by the National Educational Association to discuss and determine in the broadest way possible, what should be the proper preparation for a student seeking admission to college, was certainly one of the wisest things that could have been undertaken at the present time. A proper uniform standard for admission to college is, and ought to be a national one, and the manner in which the discussion is going on among influential teachers, scholars and authors gives strong promise of early and important results. One of the nine topics named for this discussion is mathematics, and the branch of geometry is doubtless the leading one to claim attention. Anything new or better in regard to this branch at this time ought to be examined critically and most thoroughly. For one we are glad that Professor Smith has published this new book. For it is a challenge to some of the matter and some of the method of teaching the elements of geometry in common use. The first 20 pages is the introduction, which is occupied with geometry as the doctrine of space. Then follow the themes of convergence, triangles, parallelograms, concurrents, symmetry, circle, the circle as an envelope, constructions and exercises. Thus 140 pages is devoted to linear relations. The remainder of the book (150 pages), is given to areal relations, in which the following topics appear: area, criteria of equality, miscellaneous applications, squares, proportion, similar figures, constructions, the traction problem, metric geometry, measurement of the circle, measurement of angles, the Euclidian doctrine of proportion, maxima and minima. This book is one of merit. The novelty of its methods needs to be tested in the class-room. In the hands of a competent teacher there is little doubt but that excellent results will follow.

The Academic Geometry. By William F. Bradbury, head master of the Cambridge Latin School. Part I, Plane Geometry. Messrs. Thompson, Brown & Company, Publishers. Boston, 23 Hawley St., pp. 220.

This new book contains the important theorems of plane geometry. It employs good models of demonstration with numerous exercises to test the knowledge of the pupil as he advances. The hints to teachers to aid them to get into the spirit of geometry, in order to teach are excellent. The full list of exercises at the close of the book affords ample scope for review to fix in mind the elements of Plane Geometry well to aid in further study of mathematics.

PUBLISHER'S NOTICES.

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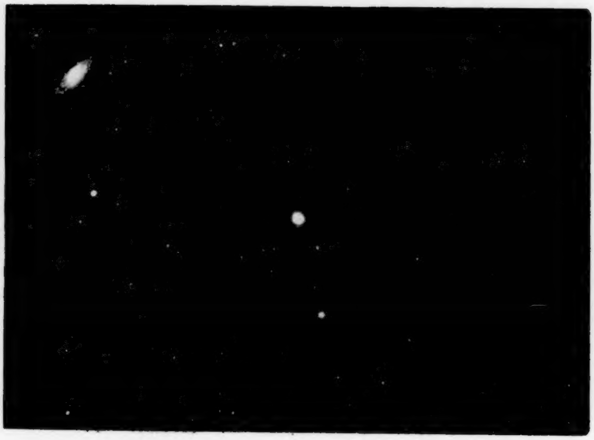

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